Transformer - Principle - Classification - EMF Equation

Objectives: At the end of this lesson you shall be able to

- **explain a transformer**
- **explain the construction of two winding transformer.**

Transformer

Transformer is a static electric device which transfer the electric energy from one circuit to other without changing the frequency and power.

The three-phase synchronous generator is used extensively to generate bulk power. The voltage levels at which this power is generated is typically in the range 11 kV to 22 kV. Electrical power is to be provided at a considerable distance from a generating station. It is possible to transmit the generated power directly but this results in unacceptable power losses and voltage drops.

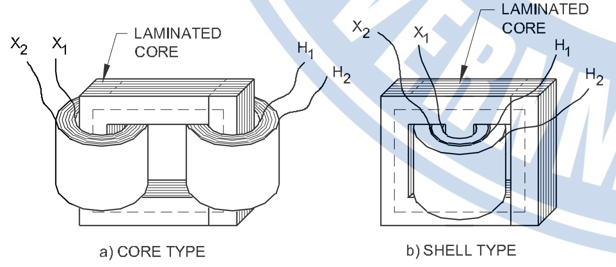
Transmission voltages vary up to the 400 kV level. This is made possible by power transformers. At the receiving end this high voltage must be reduced because ultimately it must supply three phase load at 415V or single phase load at 240V.

The transformer makes it possible for various parts of a power system to operate at different voltage levels.

Standard safety norms: Trainees can be instructed to refer the standard safety norms related with transformer in the International Electrotechnical commission (IEC - 60076-1) for the further details.

Construction: There are basically two types of iron-core construction. Fig 1a shows a **core type** transformer. It consists of two separate coils, one on each of the two opposite legs of a rectangular core.

Fig 1



a) CORE TYPE b) SHELL TYPE

TRANSFORMER CONSTRUCTIONS

Normally, this is not a desirable design. Its disadvantage is the large leakage fluxes associated with it. The large leakage fluxes cause poor voltage regulation. Therefore, to ensure that most of the flux set by the primary will link the secondary, the construction Fig 1b is employed. This is called **shell type** construction.

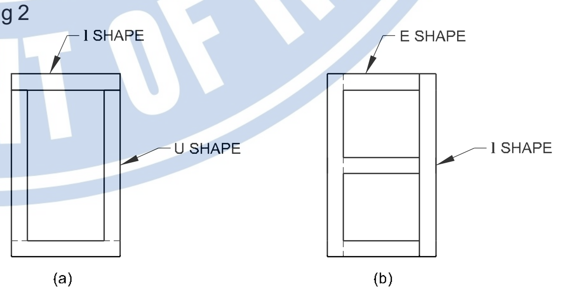
Here the two windings are wound concentrically. The higher voltage winding is wound on top of the lower voltage winding. The low-voltage winding is then located closer to the steel. This arrangement is preferable from an electrical insulating point of view. From the electrical viewpoint there is not much difference between the two constructions.

Cores may be built up of lamination silicon steel sheet. Most laminating materials have an approximate alloy content of 3% silicon and 97% iron. The silicon content reduces the magnetizing losses. Particularly, the loss due to hysteresis is reduced. The silicon makes the material brittle. The brittleness causes problems in stamping operation.

Most laminated materials are cold-rolled and often specially annealed to orient the grain or iron crystals. This provides very high permeability and low hysteresis to the flux in the direction of rolling. Transformer laminations are usually 0.25 to 0.27 mm thick for 50 Hz. operation. The laminations are coated on one side by a thin layer of varnish or paper to insulate them from each other.

Coils are pre-wound, and the core design must be such that it permits placing the coil on the core. Ofcourse, the core must then be made in atleast two sections. The laminations for the core-type transformer of Fig 1a may be made up of (└ and ┐) shaped laminations, as shown in Fig 2a. The core for the shell type transformer is normally made up of E and I shaped laminations (Fig 2b).

Fig 2



CORE CONSTRUCTION BUILT OF SEPARATE LAMINATIONS

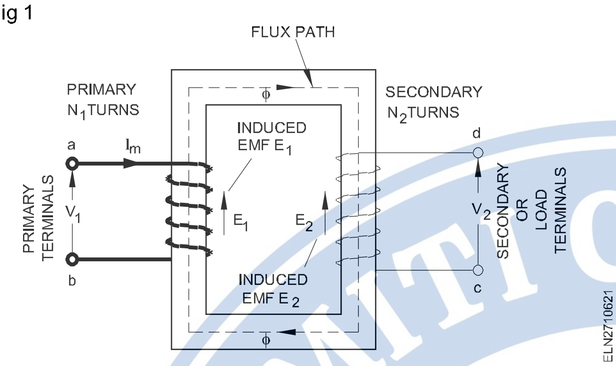
Transformer principle

Objectives: At the end of this lesson you shall be able to

- **explain the principle of the operation of a transformer**
- **derive the EMFequation of a two-winding transformer**
- **derive the transformation ratio of a transformer.**

Let us consider an ideal transformer (Fig 1) whose secondary is open and whose primary is connected to a sinusoidal voltage V_1.

Fig 1



Working principle

The transformers work on the principle of mutual induction of Faraday's law of electro - magenetic induction.

The applied voltage causes a small current to flow in the primary winding. This no-load current is meant to build up a counter-electromotive force equal and opposite to the applied voltage.

Since the primary winding is purely inductive and there is no output, the primary draws the magnetizing current I_m only. The function of this current is merely to magnetise the core. The I_m is small in magnitude and lags V_1 by 90°. This alternating current I_m produces an alternating flux ϕ which is proportional to the current and hence is in phase with it (I_m). This changing flux is linked with both the windings. Therefore, it produces self-induced EMF (E_1) in the primary which lags the flux 'ϕ' by 90^0. This is shown in vector diagram Fig 2.

The flux 'ø' produced by the primary links with the secondary winding and induces an EMF (E_2) by mutual induction which lags behind the flux 'ø' by 90°Fig 2. As the EMF induced in primary or secondary per turn is same the secondary EMFwill depend on the number of turns of the secondary.

When secondary is open circuit, its terminal voltage 'V_2' is the same as the induced EMF (E_2). On the other hand, the primary current at no load is very small, hence the applied voltage 'V_1' is practically equal and opposite to the primary induced EMF (E_1). The relationship between primary and secondary voltages Fig 2.

Hence we can say that

$$\frac{\textit{Total}\text{ emf indued in seconday' }E_2}{\textit{Total}\text{ emf induced in primary' }E_1\text{'}}$$

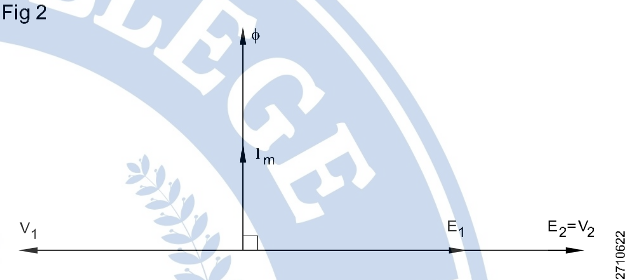
$$=\frac{N_2\times\text{emf per turn}}{N_1\ \text{x emf per turn}} \qquad \text{OR}$$

$$\frac{E_2}{E_1}=\frac{N_2}{N_1}$$

$$\text{as } E_1 = V_1 \text{ and } E_2 = V_2$$

$$\text{We have } \frac{V_2}{V_1}=\frac{N_2}{N_1}$$

Fig 2



VECTOR DIAGRAM OF AN IDEAL TRANSFORMER

Ideal Transformer on Load: When the secondary is connected to a load, secondary current flows this in turn makes the primary current to increase. How this happens is explained below.

The relationship between primary and secondary currents is based upon a comparison of the primary and secondary ampere turns.

When the secondary is open circuit, the primary current is such that the primary ampere turns are just sufficient to produce the flux 'ø' necessary to induce an EMF (E_1) that is practically equal and opposite to the applied voltage 'V_1'. The magnetising current is usually about 2 to 5 percent of the full load primary current.

When a load is connected across the secondary terminals, the secondary current - by **Lenz's law** - produces demagnetising effect. Consequently the flux and the EMFinduced in the primary are reduced slightly.

But this small change may increase the difference between applied voltage 'V_1' and the induced EMF (E_1) by say 1 percent in which case the new primary current would be 20 times the no load current.

The demagnetising ampere turns of the secondary are thus nearly neutralized by the increase in the primary ampere turns and since the primary ampere turns on no load are very small compared with the full load ampere turns.

Therefore Full load primary ampere turns $\simeq$ full load secondary ampere turns i.e $I_1N_1 \simeq I_2N_2$

so that $\frac{I_1}{I_2} \simeq \frac{N_2}{N_1} \simeq \frac{V_2}{V_1}$ **Transformation ratio**

From the above statement, it is clear that the magnetic flux forms the connecting link between the primary and secondary circuits and that any variation of the secondary current is accompanied by a small variation of the flux and therefore of the EMFinduced in the primary, thereby enabling the primary current to vary approximately, proportional to the secondary current.

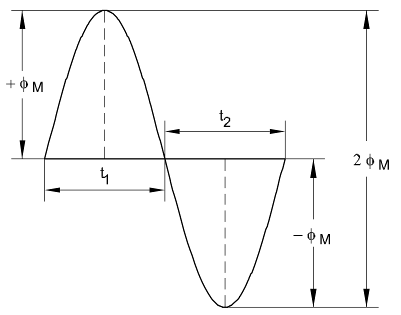
EMF equation of a transformer: Since the magnetic flux set up by the primary winding links the secondary winding, an EMF will be an induced E_2, in the secondary, in accordance with Faraday's law, namely, $E = N(\delta ø/\delta t)$. The same flux also links the primary itself, inducing in it an emf, E_1. The induced voltage must lag the flux by 90°, therefore, they are 180° out of phase with the applied voltage V_1.

Since there is no current in the secondary winding, $E_2 = V_2$. The primary voltage and the resulting flux are sinusoidal; thus the induced quantities E_1 and E_2 vary as a sine function. The average value of the induced voltage is given by

$$E_{avg} = \text{turns} \times \frac{\text{change in flux in a given time}}{\text{given time}} \quad ...(1)$$

Referring to Fig 3, it is seen that the flux change in time interval t_1 to t_2 is $2\phi_m$ where ϕ_m is the maximum value of the flux, in webers. The time interval represents the time in which this flux change occurs and equals one-half cycle of $(\frac{1}{2f})$ seconds, where f is the supply frequency, in hertz.

Fig 3



SINUSOIDAL FLUX WAVE IN CORE

It follows that

$$E_{avg} = N \times \frac{2\phi_m}{\frac{1}{2f}} = 4fN\phi_m \quad ...(2)$$

where N is the number of turns on the winding.

The effective or rms voltage for a sine wave is 1.11 times the average voltage, thus

$$E = 4.44\ f\ N\phi_m \quad ...(3)$$

Since the flux links with the primary and secondary windings, the voltage per turn in each winding is the same. Hence

$$E_1 = 4.44\ f\ N_1\phi_m \quad ...(4)$$

and

$$E_2 = 4.44\ f\ N_2\phi_m \quad ...(5)$$

where N_1 and N_2 are the number of turns in the primary and secondary windings respectively.

Transformer - simple calculations

Objective: At the end of this lesson you shall be able to

- **explain rating of transformer**
- **calculate the voltage, current and turns of primary from the secondary data and vice versa.**

Rating of transformer

The capacity of the transformers are always rated by its apparent power (volt amp - VA (or KVA), not by its true power (watt (or) KW) (ie.) KW = KVA x Cosϕ .

Example 1: A 100 KVA 2400/240V, 50 Hz. transformer has 300 turns on the secondary winding. Calculate (a) the approximate value of primary and secondary currents (b) the number of primary turns and (c) the maximum flux ϕ_m in the core.

Data given : Transformer rating 100 KVA

Frequency $f = 50$ Hz

Primary voltage $V_P = 2400$ V

Secondary voltage $V_S = 240$ V

Secondary turns $N_S = 300$

Known: $E_P = (4.44 \times f \times N_P \times \phi_m)$ volts

$$\frac{V_P}{V_S} = \frac{I_S}{I_P} \cong \frac{E_P}{E_S} \cong \frac{N_P}{N_S}$$

$$V_PI_P = V_SI_S = KVA$$

Find: Primary current I_P

Secondary current I_P

Primary turns N_P

Maximum flux Φ_m

Solution

(a) $$I_P \text{ (full load)} = \frac{KVA \times 1000}{V_p} = \frac{100000}{2400} = 41.7A$$

and $$I_S = \frac{100000}{240} = 417A$$

(b) $$\frac{V_P}{V_S} = \frac{2400}{240} = 10 = \frac{N_P}{N_S}$$

Therefore, $N_P = 10 \times N_S$

$= 10 \times 300 = 3000$ turns.

(c) $4.44 \times f \times N_P \times \phi_m = E_P$

$$\Phi_m = \frac{2400}{4.44 \times 50 \times 3000} = 0.0036 \text{ Wb.}$$

Classification of transformers

Objectives : At the end of this exercise you shall be able to

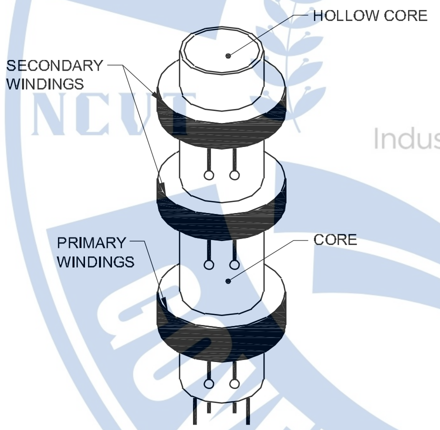
- **state the classification of transformers based on various factors.**

Classification of Transformers

1 Classification based on the type of Core Material used

- **Air core transformers** : Fig 1, air core transformers consists of a hollow non magnetic core, made of paper or plastic over which the primary and secondary windings are wound. These transformers will have values of k less than 1. Air core transformers are generally used in high frequency applications because these will have no iron-loss as there is no magnetic core material.

Fig 1



AIR CORE TRANSFORMER

2 Classification based on the shape of core

- **Core type transformers**: In Core type of transformer, the primary and secondary windings are on two separate sections/limb of core. (Fig 1 in chart 1)
- **Shell type transformers**: In this type, both the primary and the secondary windings are wound on the same section/limb of the core.These are widely used as voltage and power transformers. (Fig 2 in chart 1)
- **Ring type transformers**: In this, the core is made up of circular or semicircular laminations (Fig 3). These are stacked and clamped together to form a ring. The primary and secondary windings are then wound on the ring. The disadvantage of this type of construction is the difficulty involved in winding the primary and secondary coils. Ring type transformers are generally used as instrument transformers for measurement of high voltage and current.

3 Classification based on the Transformation ratio

- **Step-up Transformers**: Transformers in which, the induced secondary voltage is higher than the source voltage given at primary are called step-up transformers.
- **Step-down Transformers**: Transformers in which, the induced secondary voltage is lower than the source voltage given at primary are called step-down transformers.
- **Isolation transformers**: Transformers in which, the induced secondary voltage is same as that of the source voltage given at primary are called one-to-one or isolation transformers. In these transformers the number of turns in the secondary will be equal to the number of turns in the primary making the turns ratio equal to 1.

4 Single phase and three phase transformers

Transformers Fig 4 of Chart 1 are designed for use with single phase AC mains supply. Such transformers are known as single phase transformers. Transformers are also available for 3 phase AC mains supply. These are known as poly-phase transformers. Refer Fig 5 in Chart 1. Three phase transformers are used in electrical distribution and for industrial applications.

5 Classification based on application

Transformers can also be classified depending upon their application for a specialized work. There are innumerable number of applications, However a few of these are listed below:

Instrument Transformers - used in clip - on current meters, overload trip circuits etc.,

Constant voltage transformers - used to obtain stabilized voltage supply for sensitive equipments

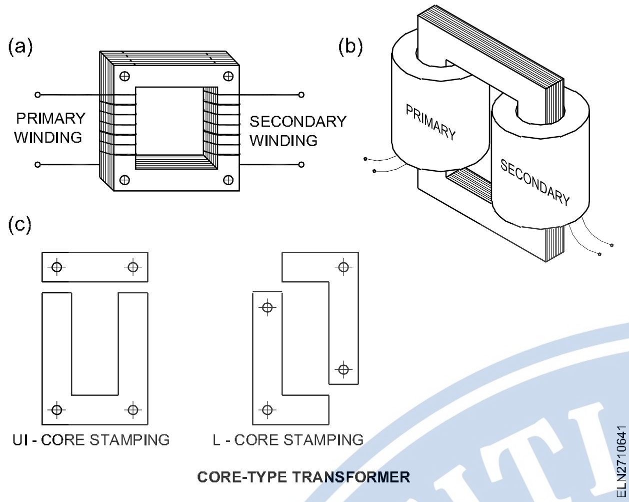
Ignition transformers - used in automobiles

Welding transformers - used in welding equipments

Dry Type Transfomers : Dry type, or air-cooled, transformers are commonly used for indoor applications where other transformer types are considered too risky.

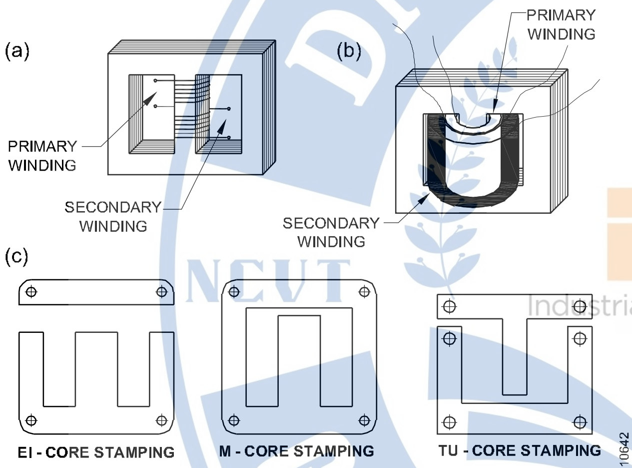
Chart - 1
Types of transformers

Fig 1 **CORE - TYPE TRANSFORMER**



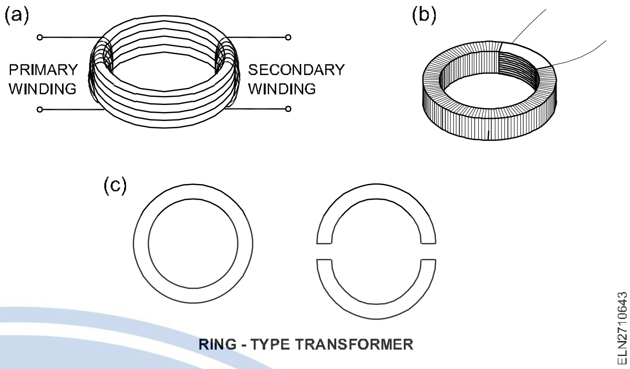
CORE-TYPE TRANSFORMER

Fig 2 **SHELL - TYPE TRANSFORMER**



SHELL-TYPE TRANSFORMER

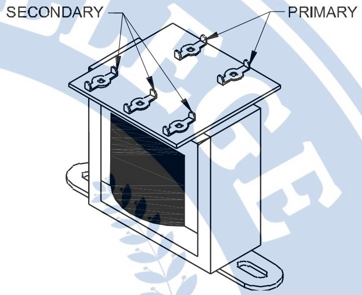
Fig 3 **RING - TYPE TRANSFORMER**



RING - TYPE TRANSFORMER

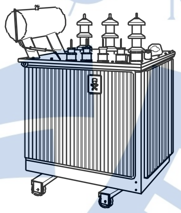
SINGLE PHASE TRANSFORMER

Fig 4



POLY - PHASE TRANSFORMER

Fig 5



POLY - PHASE TRANSFORMER

Parts and their functions of transformer

Objectives: At the end of this lesson you shall be able to

- **list out the mainparts of transformer**
- **explain the parts of a distribution transformer.**

Distribution transformer: Fig 1 shows the essential parts of a distribution transformer.

The important components of a distribution transformer are briefly described below:-

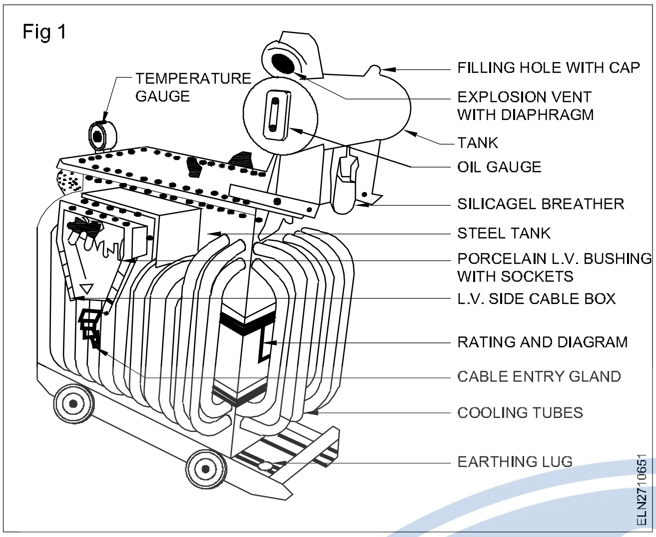
The important components of transformer are : -

1. Steel tank
2. Conservation tank
3. Temperature gauge
4. Explosion vent
5. Cooling tubes
6. Tap changer
7. Bushing termination
8. Silical gel breather
9. Buchholz relay

1 Steel tank

It is a fabricated M.S plate tank used for housing the core, winding and for mounting various accessories required for the operation of a transformer. Core is built from cold rolled grain oriented silicon steel lamination. The L.V winding is normally close to the core and the H.V winding is kept around the L.V winding.

Fig 1



2 Conservator tank

It is in the shape of a drum, mounted on the top of the transformer. An oil level indicator is fitted to the conservator tank. Conservator is connected to the transformer tank through a pipe. The conservator carries the transformer oil to a specified level. When transformer is heated up due to normal load operation, the oil expands and the level of oil in conservator tank is increased or vice versa. A pipe connected to the top of the conservator tank allows the internal air to go out or get in through the breather.

It reduces the oxidation of oil when it get contact with air.

3 Temperature gauge

It is fitted to the transformer which indicates the temperature of the transformer oil.

4 Cooling tubes

In earlier discussions, we found that the transformer is heated up, when the transformer is connected to the supply is due to iron loss and copper loss. To keep down the temperature of the windings, when the transformer is put on load, the heat generated inside the transformer should be radiated to the atmosphere. To dissipate the heat produced inside the winding and core, the transformer tank is filled with an insulating oil. The oil carries the heat to the cooling pipes where the heat is dissipated to atmosphere due to surface contact with air.

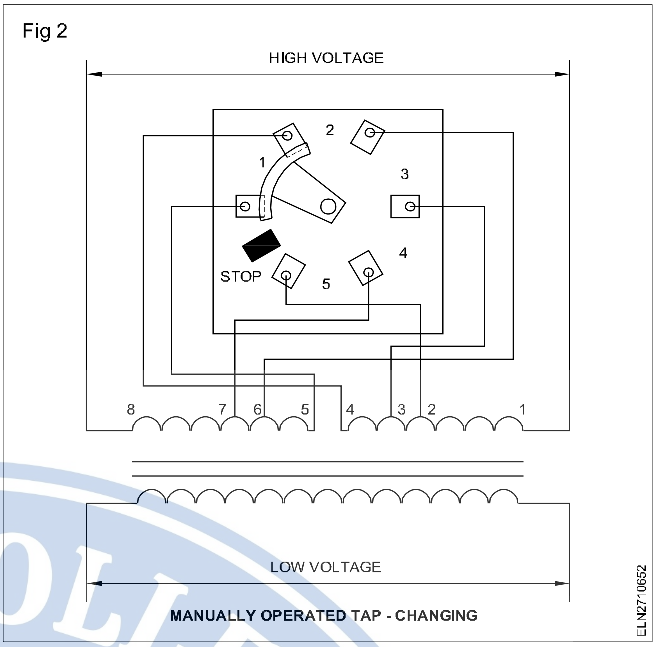
5 Tap changer

When voltages are transmitted over long distances there will be voltage drop in the conductors, resulting in lower voltage at the receiving end. To compensate this line voltage drops in the conductors, it is customary to increase the sending end voltage by tap changing transformers. These transformers may have several winding taps in their primary winding (Fig 2).

6 Porcelain bushing of transformer

This type of Transformer Bushings are used in several power industries for their robustness and they are also very cheap. Porcelain offers very good and reliable electrical insulation for a wide range of voltages as well as they have high dielectric strength too.

Fig 2



MANUALLY OPERATED TAP - CHANGING

A porcelain bushing is a hollow cylindrical shaped arrangement made by porcelain discs which is fitted to the top portion of the transformer. And the energised conductors are passed through the centre portion of the bushings.

After inserting the conductor, the ends of the porcelain bushings are tightly sealed with glaze and this arrangement ensures a prevention from any type of moisture.

The entire bushing arrangement is checked and it should not contain any leakage paths. If the operating voltage level is very high then the vacuum space of the Transformer Bushing is filled with insulating oil.

7 Protective - devices / parts of transformers:

1 Breather

Transformer oil deterioration takes place due to moisture. Moisture can appear in a transformer from three sources, viz. by leakage through gasket, by absorption from air in contact with the oil surface or by its formation within the transformer as a product of deterioration as insulation ages at high temperature.

The effect of moisture in oil is to reduce the di-electric strength, especially if loose fibres or dust particles are present.

Methods available to reduce oil contamination from moisture are:

- by the use of silica gel breather
- by the use of rubber diaphragm
- by using sealed conservator tank
- by using gas cushion
- by using thermosyphon filter

Silica gel breather

Silica gel breather is a protective device fitted to the conservator through a pipe and allows the moisture free air to and fro into the conservator when the transformer oil get heated and cools down.

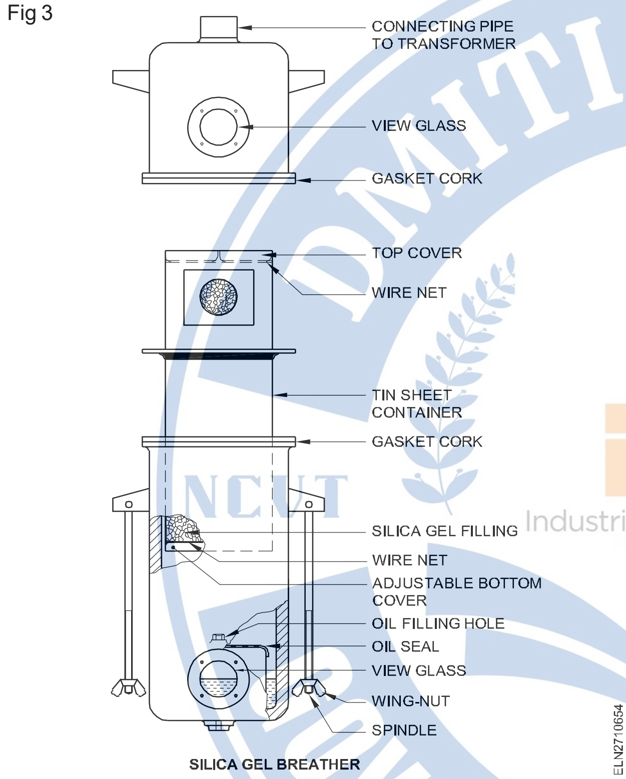
As the load and heat on a transformer reduces, air is drawn in to the conservator through a cartridge pakced with **silica gel crystals**.

The silica gel effectively dries the air and thus prevent the moistured dust entering into transformer oil. The fresh silica gel is available in blue colour. The colour of the silica gel changes to pure white or light pink colour as it absorbs moisture from air.

To recondition silica gel either it can be dried in sun or it could be dry roasted on a frying pan kept over a stove. Fig 3 & 4 show a cross-sectional view of such a silica gel breather.

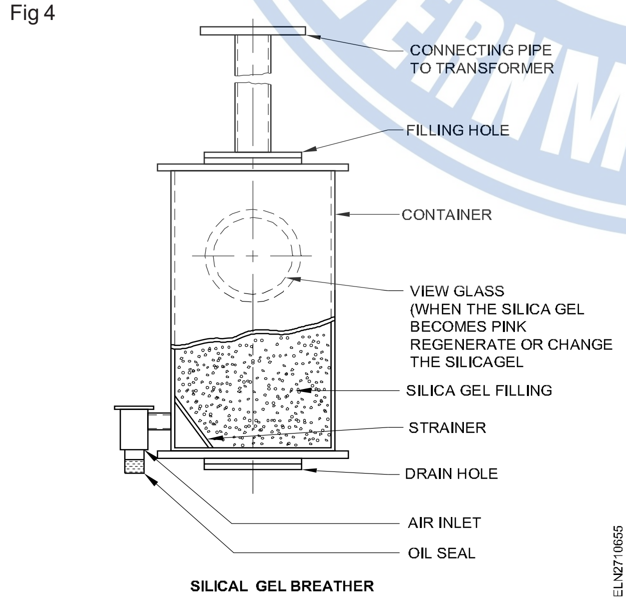
The oil seal at the bottom of the breather absorbs the dust particles that are present in the air entering the conservator.

Fig 3



SILICA GEL BREATHER

Fig 4



SILICAL GEL BREATHER

2 Buchholz relay

Buchholz relay is a gas operated - protective device which is connected between the transformer oil tank and the conservator tank.

If a fault is present inside a transformer, it may be indicated by the presence of bubbles (gas) in the transformer oil. Presence of gas could be viewed from class in window of by the Buchholz relay.

The relay comprises of a cast iron chamber which have two floats Fig 5. Top float assembly operates during initial stages of gas/air bubble formation due to minor fault in the transformer.

When sufficient gas bubbles formed around the top float, the float operates in pneumatic pressure principle to close an electric circuit through mercury switch which causes the siren or alarm bell to operate to caution the operator.

On hearing the alarm sound the operator takes necessary preventive steps to safeguard the transformer.

If any major fault like earth, fault etc, occurs in the transformer then the production of gas bubbles are more severe and hence the bottom float activates the mercury switch and closes the relay contacts.

Closing of the bottom relay contacts trips the transformer circuit breaker and opens the transformer from main line to protect the transformer from further damage.

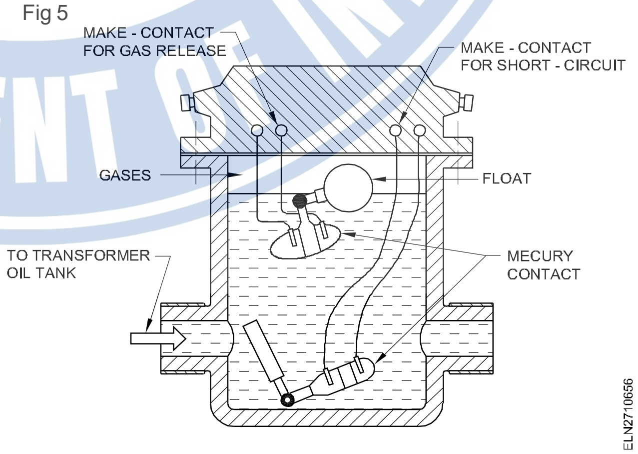
3 Explosion vent

It is a pressure release device fitted to the transformer. The mouth of the explosion pipe is tightly closed using either a thin glass or laminated sheet.

If, by any, chance the transformer is overheated either due to short circuited or sustained overload, the gases produced inside the transformer tank creates tremendous pressure which may damage the tank.

On the other hand the pressure built inside the transformer may break the glass/laminated diaphragm of the explosion pipe and thereby the tank can be saved from total damage.

Fig 5



Autotransformer - principle - construction - advantages - applications

Objectives: At the end of this lesson you shall be able to
- **state the principle of auto-transformer**
- **describe the construction of auto-transformer**
- **state the advantages, disadvantages and appliations of auto-transformer.**

Auto transformer

- The auto transformer is a transformer having single winding which acts as primary as well as secondary winding.
- The auto transformer works on the principle of self inductance of Faraday's Law of electro - magnetic induction.

The induced voltage per turn was the same in each and every turn linking with the common flux in the core.

Therefore, fundamentally it makes no difference in the operation whether the secondary induced voltage is obtained from a separate winding linked with the core, or from a portion of the primary turns. The same voltage transformation results in both the situations.

Construction

An ordinary two winding transformer may also be used as an auto-transformer by connecting the two windings in series and applying the voltage across the two, or merely to one of the windings.

It depends on whether it is desired to keep the voltage down or up, respectively.

Figs 1 and 2 show these connections.

Considering Fig 1, the input voltage V_1 is connected to the complete winding a - c and the load R_L is across a portion of the winding, that is, b - c. The voltage V_2 is related to V_1 as in a conventional two winding transformer, namely,

$$V_2 = V_1 \times \frac{N_{bc}}{N_{ac}}$$

Where N_{bc} and N_{ac} are the number of turns on the respective windings. The ratio of voltage transformation in an autotransformer is the same as that for an ordinary transformer.

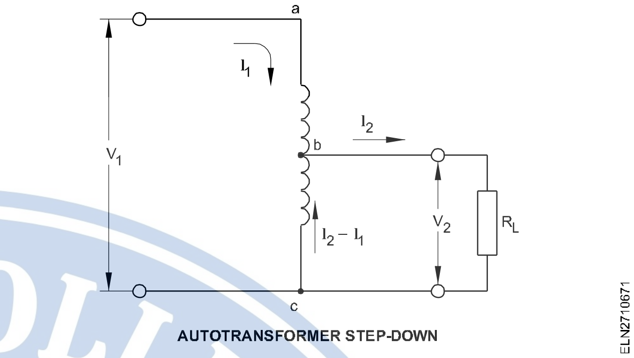
$$a = \frac{N_{bc}}{N_{ac}} = \frac{V_2}{V_1} = \frac{I_1}{I_2}$$

with a < 1 for step down.

Advantages : Auto-transformers:

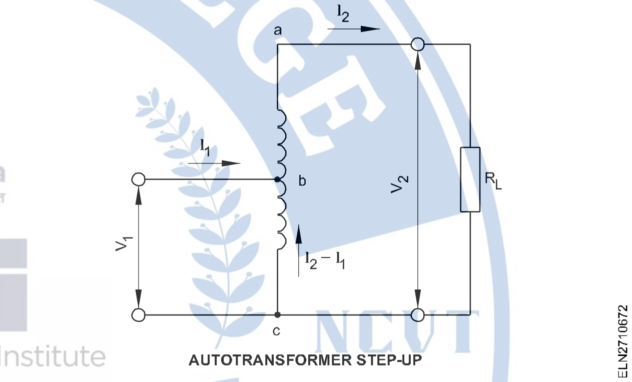
- less cost
- have better voltage regulation
- are smaller

Fig 1



AUTOTRANSFORMER STEP-DOWN

Fig 2



AUTOTRANSFORMER STEP-UP

- are lighter in weight
- are more efficient when compared with two winding transformers of the same capacity.

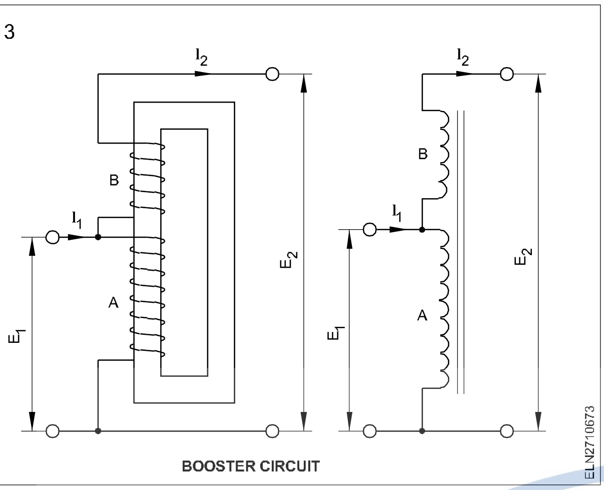
Disadvantages: Auto-transformers have two disadvantages.

- An auto-transformer does not isolate the secondary from the primary circuit.
- If the common winding bc becomes open circuit, referring to Fig 1 or 2, the primary voltage can still feed the load. With a step-down auto-transformer this could result in burnt out secondary load and/or a serious shock hazard, particularly if the step down ratio is high.

Application: The common applications are:

- fluorescent lamps (where supply voltage is less than the rated voltage)
- reduced voltage motor starter
- series line boosters for fixed adjustment of line voltage (Fig 3)
- servo-line voltage correctors.

Fig 3



BOOSTER CIRCUIT

Instrument transformers - current transformer

Objectives: At the end of this lesson you shall be able to
- **state the necessity, types and principle of the instrument transformer**
- **explain the construction and connection of the current transformer**
- **state the precautions to be followed while using the current transformer.**

Necessity of instrument transformers: Transformers used in conjunction with measuring instruments for measurement purposes are called **'instrument transformers'**. the actual measurements are done by the measuring instruments only.

Where the current and voltage are very high, direct measurements are not possible as, these current and voltage are too large for reasonably sized instruments and the cost of the meter will be high.

The solution is to step-down the current and voltage with instrument transformers, so that, they could be metered with instruments of moderate size.

These instrument transformers electrically isolate the instruments and relays from high current/voltage lines thereby reducing danger to the men and equipment. To obtain perfect isolation, the secondary of the instrument transformers and the core should be grounded.

Type of instrument transformers: Three are two types of instrument transformers.

- Current transformer
- Potential transformer

The transformer used for measurement of high current is called 'current transformer' or simply 'CT'

the transformer used for high voltage measurement is called 'voltage transformer or potential transformer' or simply 'PT' in short.

Principle: Instrument transformers work on the principle of mutual induction similar to the two winding transformers.

In the case of an instrument transformer, the following design features are to be considered.

Core: In order to minimise the error, the magnetizing current must be kept low. This means the cores should have low reactance and low core losses.

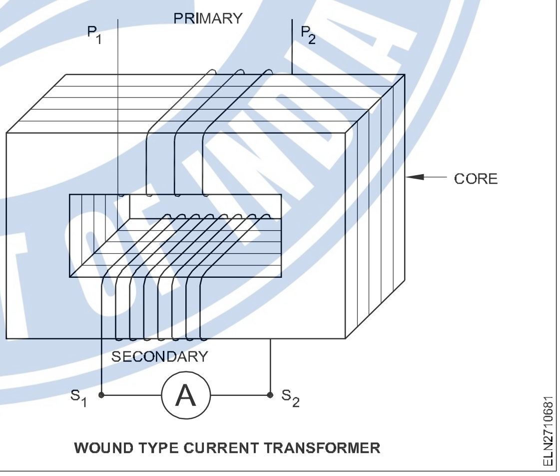
Winding: The winding should be close together to reduce the secondary leakage reactance; otherwise the ratio error will increase. In the case of a current transformer the winding must be so designed as to withstand the large short circuit current without damage.

Current transformers - types of construction and connection

The following are the different types of current transformers.

Wound type current transformer: This is one in which the primary winding is having more than one full turn wound on the core (Fig 1)

Fig 1



WOUND TYPE CURRENT TRANSFORMER

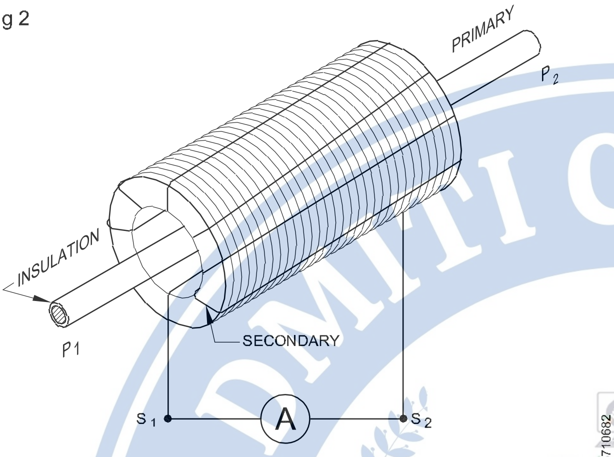
Fig 1 shows the connections of a wound type current transformer having a rectangular type of core. In general the ammeter is arranged to give full scale deflection with 5A or 1A when connected to the secondary of the current transformer.

The ratio between the primary and secondary turns of the current transformer decides the primary current which could be measured with fixed secondary current rating of 5 or 1 amp.

For example if the primary current is 100 amps and there are two turns in the primary, then the full load primary ampere turns is 200. Consequently, to circulate 5 amps in the secondary, the number of secondary turns must be 200/5, that is 40 turns.

Ring type current transformer: This has an opening in the centre to accommodate a primary winding through it Fig 2 shows a ring type current transformer with single turn primary. In this current transformer, the insulated conductor that carries the current to be measured passes directly through an opening in the transformer assembly.

Fig 2



RING TYPE CURRENT TRANSFORMER

If there are 20 turns in the secondary having a current range of 5 amps, this current transformer according to the transformation ratio, could measure a primary current of 100 amps.

Clamp on or clip on ammeters work on this principle only but the core is made such that it can open to pass the insulated conductor and then get closed to complete the magnetic circuit.

Bar type current transformer: This is one in which the primary winding consists of a bar of suitable size and secondary winding and core assembly material forming an integral part of the current transformer (Fig 3).

Dry type current transformer :This is one which does not require the use of any liquid or semi-liquid material for the purpose of cooling.

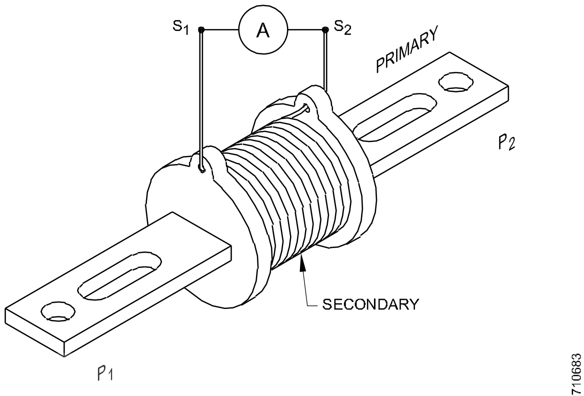
Oil immersed current transformer: This is one which requires the use of an oil of suitable characteristic as insulating and cooling medium.

General terms used

Accuracy class: Accuracy class is a designation assigned to a current transformer the errors of which remain within the specified limits under prescribed conditions of use. The standard accuracy classes for measuring current transformers shall be 0.1, 0.2, 0.5, 1.0, 3.0 and 5.0.

Precautions while using the current transformer : In a current transformer the secondary current depends upon the primary current. Futher the secondary of the current transformer could be assumed to be almost short circuited as the ammeter resistance is extremely low.

Fig 3



BAR TYPE CURRENT TRANSFORMER

In any case, the secondary winding of the current transformer should not be open circuited. This may happen when the ammeter become open circuited or when the ammeter is removed from the secondary.

In such cases the secondary should be short circuited. If the secondary is not short circuited, in the absence of secondary ampere-turns, the primary current will produce abnormally high flux in the core thereby heating up the core and resulting in burning out the transformer.

Further secondary will produce a high voltage across its open terminals endangering safety. In addition to earthing non-current carrying metal parts of the current transformer, we have to earth one end of the secondary of the current transformer to prevent a high static potential difference in case of open circuit. It also serves as a safeguard in case of insulation failure.

Specification of a current transformer: While purchasing a current transformer, the following specifications need to be checked.

- Rated voltage, type of supply and earthing conditions (for example, 7.2 kV, three phase, whether earthed through a resistor or solidly earthed).
- Insulation level
- Frequency
- Transformation ratio
- Rated output
- Class of accuracy
- Short time thermal current and its duration

Standard values of rated primary current: The standard values in amperes of rated frequency are 10, 15, 20, 30, 50, 75 amperes and their decimal multiples.

Standard values of rated secondary current: The standard values of rated secondary current shall be either 1 ampere or 5 amperes.

Potential transformer

Objectives: At the end of this lesson you shall be able to
- **explain the construction and connection of the potential transformer**
- **state specification of PT.**

Potential transformer

Construction and connection: The construction of a potential transformer is essentially the same as that of a power transformer. The main difference is that the volt-ampere rating of a potential transformer is very small.

To reduce the error in a potential transformer, it is required to provide a short magnetic path, good quality of core materials, low flux density and proper assembling and interlaying of cores.

To reduce resistance and leakage reactance, thick conductors are used and the two windings are kept as close as possible.

The core may be of shell or core type construction. Shell type construction is normally used for low voltage transformers.

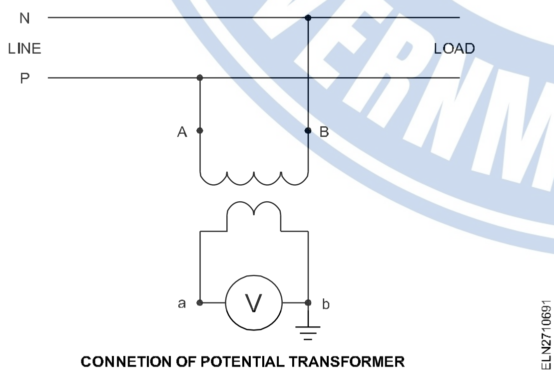
The primary and secondary windings are coaxial to reduce the leakage reactance to the minimum. In order to simplify the insulation problem, generally a low voltage winding (secondary) is put next to the core.

The primary winding may be of a single coil in the case of low voltage transformers but in the case of high voltage transformers the winding is divided into a number of short coils.

Fig 1 shows the connections of a potential transformer. In general, the voltmeter connected to the secondary of the potential transformer is arranged to give full scale deflection at 110 volts.

The ratio between the primary and secondary turns of the potential transformers decides the primary voltage which could be measured with the fixed secondary voltage rating of 110 volts (Fig 1).

Fig 1



CONNETION OF POTENTIAL TRANSFORMER

If the primary turns are four, the secondary turns are two and the primary is connected to a voltage source of magnitude 220 volts, the secondary voltage will be 110 volts according to the transformation ratio.

Precautions to be followed while using a potential transformer: The assembly comprising of the chasis frame work and the fixed part of the metal casing of the voltage transformer shall be provided with two separate, readily accessible, corrosion-free terminals marked legibly as earth terminals.

Specification of a potential transformer: While purchasing a potential transformer, the following specifications need to be checked.

- Rated voltage, type of supply and earthing conditions (for example 6.6 KV, 3 phase solid earthed)
- Insulation level
- Frequency
- Transformation ratio
- Rated output
- Accuracy class
- Winding connection
- Rated voltage factor
- Service conditions including whether voltage transformers are for indoor or outdoor use, whether for use at unusally low temperatures, altitudes (if over 1000 metres), humidity and any special conditions likely to exist or arise, such as exposure to steam or vapour, fumes, explosive gases, excessive dust, vibrations etc.
- Special features, such as limiting dimensions.
- Whether the voltage transformer is required for connection between the star point of the generator and earth.
- Any additional requirement for voltage transformers for protective purposes.
- Whether the installation is electrically exposed or not.
- Any other information.
- Three phase assembly with one multi-tap secondary

Standard rating of potential transformer

Rated frequency: The rated frequency shall be 50 Hz.

Rated primary voltage: The rated primary nominal system voltage of a 3-phase transformer. 0.6, 3.3, 6.6, 11, 15, 22, 33, 47, 66, 110, 220, 400, and 500 KV.

The standard value of primary voltage of a single phase transformer connected between one line of a 3-phase system and neutral point shall be $\frac{1}{\sqrt{3}}$ times of the above values of the nominal system voltages.

The rated secondary voltage: The rated value of secondary voltage for a single phase transformer or for a 3-phase transformer shall be either 100 and 110V.

Transformer losses - OC and SC test - efficiency - Voltage Regulation

Objectives: At the end of this lesson you shall be able to
- **state the type of losses occured in transformer**
- **explain Iron (No - load) losses and copper (load) losses in transformer.**

Losses

There are two type of losses occured in the transformer such as iron (core) loss (Hysterisis + eddy current) and copper (Ohmic) or load loss

Iron (or) No-load losses: The no load losses consist of two components i.e hysteresis and eddy current loss.The hysteresis loss due to the cyclic variation of the magnetic flux in the ferrous metal.

The eddy current occurs because of the changing flux in the core,(according to Lenz's law) inducing a voltage in the core. As a result, circulating eddy currents set up in the core with subsequent I^2R loss. This is also called as **iron loss (or) core loss (or) constant losses**.

As the core flux in a transformer remains practically constant at all loads, the core-loss is also constant at all loads. This is also known as no-load losses.

Hysteresis loss W_h = $K_h B^{1.6}_m$ watts
Eddy current loss W_e = $K_e f^2 K_f B_m^{\ 2}$
where K_h = the hysteresis constant
K_f = the form factor
K_e = the eddy current constant

These losses are minimised by using steel of high silicon content (from 1.0 to 4.0 percent) for the core and by using very thin laminations.

Silicon steel has a high saturation point, good permeability at high flux density, and moderate losses. Silicon steel is widely used in power transformers, audio output transformers and many other applications.

The input power of a transformer, when on no-load, measures the core-loss.

Copper (or) Load losses: This loss is mainly due to the ohmic resistance of the transformer windings. The load current through the resistances of the primary and secondary windings creates I^2R losses that heat up the copper wires and causes voltage drops. This loss is also called **copper losses (or) variable losses**. Copper losses are measured by the short circuit test.

The core loss in a transformer is a constant loss for all load conditions. The copper loss varies proportionally to the square of the current.

Open Circuit (O.C) test of a transformer

Objective: At the end of this lesson you shall be able to
- **explain the method of conducting an open circuit test**
- **calculate the exact iron loss.**

The open circuit

The open circuit test is performed to determine the no-load losses or the core losses.

In this test, a rated voltage is applied to one winding, usually the low-voltage winding for safety reasons, while the other is left open-circuited. The input power supplied to the transformer represents mainly core losses. Since the no-load current is relatively small the copper loss may be neglected during this test.

The circuit instruments are shown in Fig 1. The wattmeter indicates the core loss. The voltmeter will register the rated voltage. The ammeter reading in conjunction with voltage will provide the necessary data to obtain information about the magnetizing current.

The core loss can be measured on either side of the transformer. For instance, if a 3300/240V transformer were to be tested the voltage would be applied to the secondary side, since 240V is more readily available.

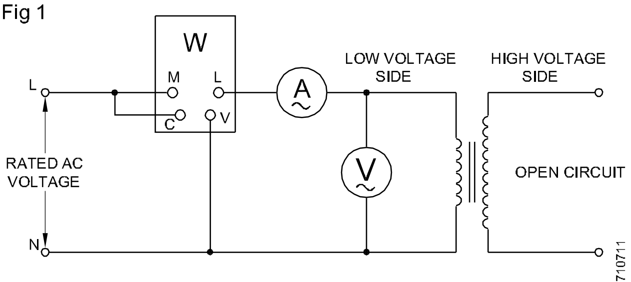
The core loss measured on either side of the transformer would be the same, because 240V is applied to a winding that has fewer turns than the high voltage side. Thus the volt/turn ratio is the same. This implies that the value of the maximum flux in the core is the same in either case. The core loss depends on the maximum flux.

The frequency of the o.c. test supply should be equal to the rated frequency of the transformer.

The actual (exact) iron loss (W_i) can be calculated by the formula

Iron loss = $W_i = W_0$ - no load copper loss
$W_i = W_o - (I_0)^2 R$

Fig 1



OPEN CIRCUIT TEST CONNECTIONS

W0 = Wattmeter reading on no load

No Load copper loss = $(I_0)^2 R$

R = Resistance of winding in which the OC test calculated

I_0 = No - load current

Short circuit (S.C) test of a transformer

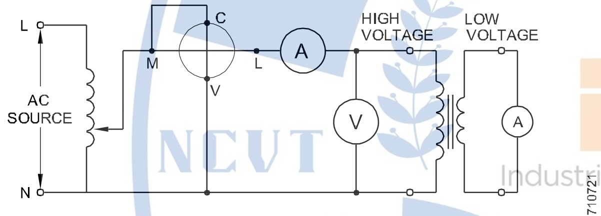
Objectives: At the end of this lesson you shall be able to

- **explain the method of conducting the short circuit test on a single phase transformer**
- **calculate the equivalent resistance and equivalent reactance of the transformer, with respect to high voltage circuit**
- **calculate the copper loss.**

Short circuit test:

A short circuit test is required to determine the transformer equivalent circuit parameters and copper losses. The connected diagram for the short circuit test is shown in Fig 1.

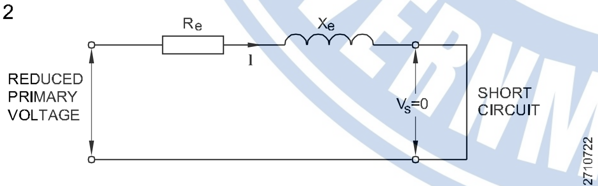
Fig 1



CONNECTION DIAGRAM

The low voltage side of the transformer is short circuited. A reduced voltage applied on the high voltage winding of the transformer such that the rated current flows through the ammeter. In this condition the impedance of the transformer is merely as equivalent impedenence (Fig 2).

Fig 2



EQUIVALENT CIRCUIT

The test is performed on the high voltage side because it is convenient to apply a small percentage of the rated voltage. In the case of a 3300V/240V transformer, it is easier and more accurate to deal with 5% of 3300V than with 5% of 240V.

With the primary voltage greatly reduced, the flux will be reduced to the same extent. Since the core loss is somewhat proportional to the square of the flux, it is practically zero.

Thus a wattmeter used to measure the input power will indicate the copper losses only; the output power is zero. From the input data obtained from the instruments, the equivalent reactance, can be calculated. All the values calculated are in terms of high voltage side.

R_e is equivalent resistance

X_e is equivalent reactance

R_{eH} is equivalent resistance on high voltage side

X_{eH} is equivalent reactance on high voltage side

Z_{eH} is equivalent impedance on high voltage side

$$R_{eH} = \frac{P_{SC}}{I^2_{SC}} \text{ ohms}$$

$$Z_{eH} = \frac{V_{SC}}{I_{SC}} \text{ ohms}$$

$$\text{and } X_{eH} = \sqrt{Z^2_{eH} - R^2_{eH}} \text{ ohms}$$

where I_{sc}, V_{SC} and P_{SC} are the short circuit amperes, volts and watts respectively, and R_{eH}, Z_{eH} and X_{eH} are equivalent Resistance, Impedance and Reactance respectively in terms of high voltage side.

Efficiency of transformer

Objectives: At the end of this lesson you shall be able to

- **calculate efficiency from the losses**
- **state the condition for maximum efficiency**
- **define all-day efficiency of a distribution transformer.**

Efficiency of transformer:

In general, the efficiency of any electrical apparatus is

$$\eta = \frac{\text{output power}}{\text{input power}} = \left|\frac{\text{output power}}{\text{output power} + \text{losses}}\right| \quad .....(1)$$

where η is the symbol used to denote efficiency. When equation (1) is multiplied by the factor 100, the efficiency will be in percent.

The efficiency of a transformer is high and in the range 95 to 98%. This implies that the transformer losses are as low as 2 to 5% of the input power.

While calculating the efficiency, it is generally much better to determine the transformer losses rather than measured the input and output powers directly.

In transformer, the open circuit test yields the core losses and the short circuit test provides the copper losses. Thus the efficiency can be determined from these data with reasonable accuracy.

The transformer ratings are based on output KVA (MVA). Therefore, the equation for efficiency may be written as

$$\eta = \left|\frac{\text{KVA}_{\text{out}} \times \text{PF}}{(\text{KVA}_{\text{out}} \times \text{PF}) + \text{Copper loss} + \text{core loss}}\right|$$

Condition for maximum efficiency:

The efficiency of a transformer is at a maximum when the fixed losses are equal to the variable losses. In other words, when the copper losses is equal to the iron losses, the efficiency is maximum.

Example: A transformer with a rating of 10 KVA 2200/220V 50 Hz was tested with the following results.

Short circuit test power input = 340 W

Open circuit test power input = 168 W

Determine

(i) the efficiency of this transformer at full load

(ii) the load at which maximum efficiency occurs.

The load power factor is 0.80 lagging.

Solution

(i) Efficiency at full load, η_{FL}

$$\eta = \frac{P_{out}}{P_{in}} = \frac{(10 \times 10^3 \times 0.8)\ 100}{(10 \times 10^3 \times 0.8) + \text{Cu loss} + \text{Iron loss}}$$

$$= \frac{(10000 \times 0.8)\ 100}{(10000 \times 0.8) + 340 + 168}$$

$$= 94.0\%.$$

(ii) The maximum efficiency occurs at a load when the copper loss = core loss.

Thus the copper loss = core loss = 168 W.

Let the current at full load = I.

The current at maximum efficiency = I'.

Then, the copper loss at full load = $I^2 R_{eq}$ = 340 W

the copper loss at h_{max} = $(I')^2 R_{eq}$ = 168 W.

$$\text{Therefore,} \quad \frac{I^2 R_{eq}}{I'^2 R_{eq}} = \frac{340}{168}$$

$$\text{or} \quad I' = I\sqrt{\frac{168}{340}}$$

This is the factor by which the power decreases,

$$\text{Therefore,} \quad P_{atmax\eta} = \sqrt{\frac{168}{340}} \times (10000\text{x}0.8)$$

$$= 5623 \text{ W}$$

$$P_{atmax\eta} = 5623 \text{ W}$$

$$= 70.26\% \text{ of } 8000 \text{ W}$$

$$= 0.7026 \text{ of full load.}$$

or

$$\text{Therefore,} \quad \eta_{max} = \frac{5623}{5623 + 168 + 168} \times 100$$

$$= 94.36\%.$$

All day efficiency

Lighting transformers and most distribution transformers will not have full load for all the 24 hours in a day. To keep the operational efficiency of such distribution transformers are designed to have their maximum efficiency at a lower value than full load.

Allday efficiency

$$\frac{\text{Output in 24 houea}}{\text{Output in 24 hours losses in 24 hours}}$$

Aallday

$$= \frac{\text{Output KWh 24 houea}}{\text{Output KWh (24 hours) + losses KWh (24 hours)}}$$

Here, the iron loss is considered through out the period where as copper loss depends up on the period for which transformer is loaded and percentage load.

Example: A 100 KVA distribution transformer has a full load loss of 3 KW. At full load the losses are equally divided between iron and copper loss. During a certain day the transformer connected to the lighting load operated with loads as given below.

a On full load, unity PF 3 hours.

b On half full load, unity PF 4 hours.

c Negligible and during the remaining part of the day.

Calculate the all day efficiency.

Solution

As the load is primarily lighting, the PF = 1.0.

(a) Output energy at FL in 3 hours

= 100 KVA x 1 x 3 = 300 KWh

(b) Output energy at 1/2 FL in 4 hours

= 100 x 1/2 x 1 x 4 = 200 KWh.

Energy wasted in kWh during full load

= 3 KW x 3h = 9 KWh.

At full load

Iron loss = copper loss = 3.0¸2 = 1.5 KW.

Copper loss at 1/2 full load

= 1.5 x $(1/2)^2$ = 1.5/4 KW.

Total energy loss during half full load

= iron loss for 4 hours + copper loss for 4 hours

= (1.5 x 4) + (1.5/4 x 4)

= 6 + 1.5 = 7.5 KWh.

The transformer has no load for

= (24 - 7) hours = 17 hours.

Constant loss for 17 hours

= 1.5 x 17 = 25.5 KWh.

The total loss for 24 hours= (9 + 7.5 + 25.5) KWh = 42

$$\eta_{\text{all day}} = \frac{\text{Output KWh 24 hours}}{\text{Output KWh(24 hours) + losses (24 hours)}}$$

$$\text{KWh} = \frac{(300 + 200)}{(300 + 200) + 42} = 0.922$$

$$\eta_{\text{allday}} = 92.2\%$$

Voltage regulation of transformers

Objectives: At the end of this lesson you shall be able to
- **define the voltage regulation of a transformer**
- **calculate the voltage regulation of a transformer.**

Voltage regulation:

The voltage regulation of a transformer is the difference between the no-load and full load secondary voltage expressed as a percentage of the full load voltage. The primary or applied voltage must remain constant.

This is an additional condition that must be fulfilled in the case of transformers.

Also, the power factor of the load must be stated since the voltage regulation does depend on the load power factor.

In general,

Voltage regulation =

$$\frac{V_{\text{noload}} - V_{\text{load}}}{V_{\text{load}}} \text{ x } 100\%$$

Let V_0 = Secondary terminal voltage at no-load

V_S = Secondary terminal voltage at load.

$$\text{Then \% regulation} = \frac{V_o - V_S}{V_S} \text{ x } 100$$

The numerical values employed in the calculations depend on which winding is used as a reference for the equivalent circuit. Similar results are obtained whether all impedance values are transferred to the primary or to the secondary side of the transformer.

Example:

The secondary voltage of 11KV/440V, 100KVA transformer is 426 V at no-load. Under the full load condition, the same is 410V at 0.92 Power factor. Calculate the percentage voltage regulation of the transformer.

solution:

$$\text{\% of Voltage regulation} = \frac{V_o - V_S}{V_S} \text{ x } 100$$

$$\text{\% of Voltage regulation} = \frac{426 - 410}{410} \times 100$$

$$= \frac{16}{10} \times 100$$

$$= 3.9\%$$

Parallel operation of two single phase transformers

Objectives: At the end of this lesson you shall be able to
- **state the necessity of parallel operation of transformers**
- **state the conditions to be full filled for the parallel operation of transformers**
- **explain how to determine the polarity terminals of transformer.**

Necessity of parallel operation of transformers

1 When the power demand of the load increases, two or more transformer may be operated in parallel.

2 When the power demand decreases, only required numbers of transformer may be operated with their full load capacity. Where as the remaining transformers may be switched "OFF" and taken for general maintenance/service.

3 Thus the efficiencies and life of the transformers increases and the losses are reduced.

4 It provides more reliability of power i.e., even one transformer fails or become out of service, other transformers will supply to the certain amount of load.

5 It is not economical to manufacture a single very large capacity transformer. Thus operationg two or more numbers of optimal capacity transformers in parallel is more economical.

6 It is easy to plan the maintenance schedule of the transforemers, hence the cost of maintenance and spares are reduced.

Conditions

1 the same voltage ratio

2 Input voltage must be same

3 the same per unit (or percentage) impedance

4 the same polarity

5 the same phase sequence and zero relative phase displacement, for 3 phase transformers.

Of these (4) and (5) are absolutely essential (1) and (2) must be satisfied to a close degree.

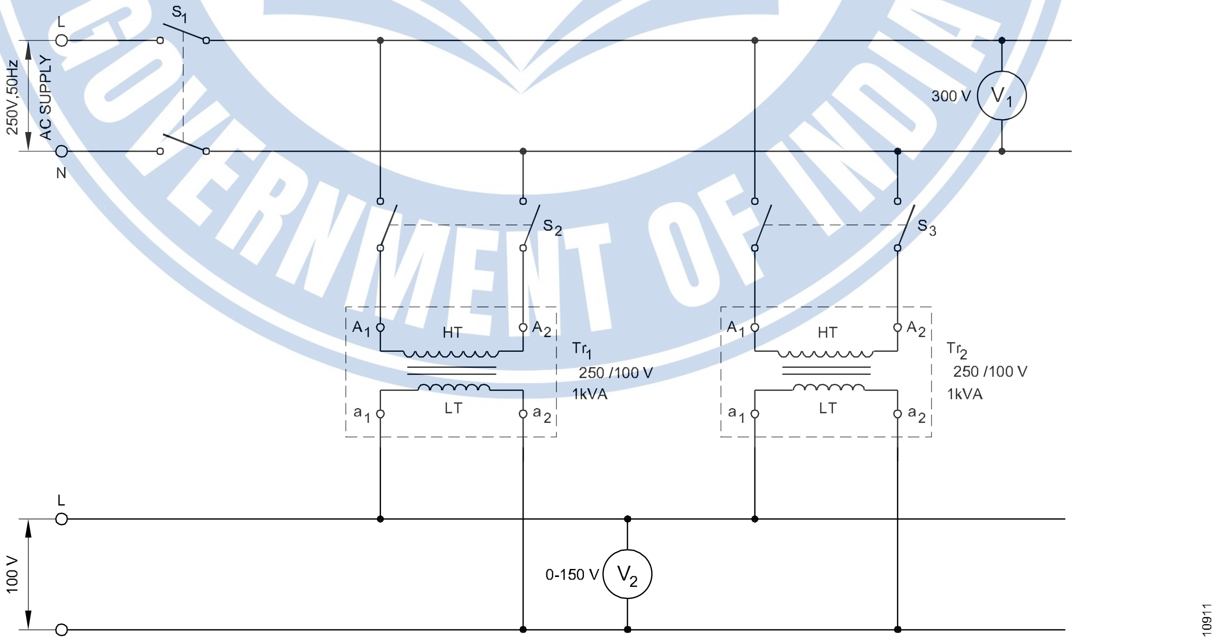
There is more allowance for a wide extent with (3), but the more nearly it is true, the better will be the load division between several transformers.

Parallel operation

Fig 1 shows two single phase transformers connected in parallel with their primary windings connected to the same supply and their secondary windings supplying a common load.

When operating two or more transformers in parallel, to have satisfactory performance the following conditions should be met

Fig 1



TWO SINGLE PHASE TRANSFORMERS CONNECTED IN PARALLEL

Voltage ratio: If voltage readings on the open secondaries of various transformers, to be run in parallel, do not show identical values, there will be circulating currents between the secondaries (and therefore between primaries also) when the secondary terminals are connected in parallel. The impedances of transformers is small, so that a small percentage voltage difference may be sufficient to circulate considerable current and cause additional I^2R loss.

When secondaries are loaded, the circulating current will tend to produce unequal loading conditions. Thus it may be impossible to take the full load output from the parallel connected group without one of the transformers becoming excessively heated.

Impedance: The currents carried by the two transformers are proportional to their ratings:

- if their numerical or ohmic impedances are inversely proportional to those ratings, and
- their per unit impedances are identical.

A difference in the quality factor (i.e the ratio of reactance to resistance) of the per unit impedance results in a divergence of the phase angle of the currents, so that one transformer will be working with a higher and the other with a lower power factor than that of the combined output.

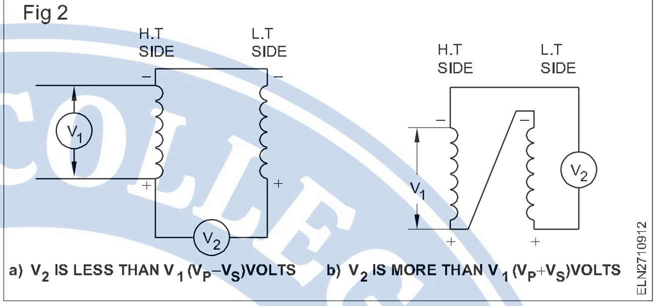
Verification of terminals or Polarity: When two or more transformers are to be connected in parallel on their primary and secondary sides, the terminals of the same polarity only can be connected together, otherwise a heavy circulating current will be produced between the windings.

Standard procedure to determine the polarity is explained below:-

- connect one end of the high voltage winding to one end of the low voltage winding as shown in Fig 2a.
- Connect a voltmeter between the two open ends.
- Apply a voltage not greater than the rated voltage of the winding to either high or low voltage winding.

If V_2 reads less than V_1 (Fig 2a) the primary and secondary emfs are in opposition. The marking on primary will be A_1 for +ve side and A_2 for –ve side and a_1 for +ve side of secondary and a_2 for –ve side. If the connections are made (Fig 2b) the voltmeter V_2 will read more than V_1. Thereby it is ascertained opposite ends are connected.

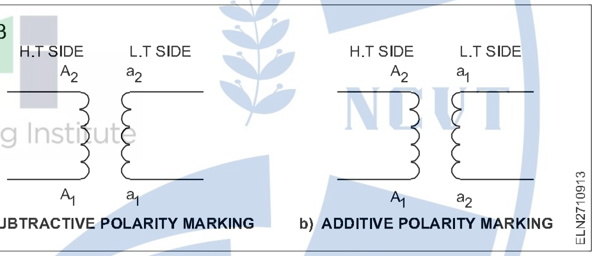
Fig 2



a) V_2 IS LESS THAN V_1 (V_P-V_S)VOLTS b) V_2 IS MORE THAN V_1 (V_P+V_S)VOLTS

If in transformer has similar ends in one side (Fig 3a) the polarity marking is said to be subtractive polarity marking on the other hand if the opposite ends are in one side (Fig 3b) the polarity marking is called as additive polarity marking.

Fig 3



a) SUBTRACTIVE POLARITY MARKING b) ADDITIVE POLARITY MARKING

Series (Secondary only) operation of transformers

Objectives: At the end of this lesson you shall be able to
- **state the necessity of series operations**
- **state the conditions to be fulfilled for series operation**

Series operation:

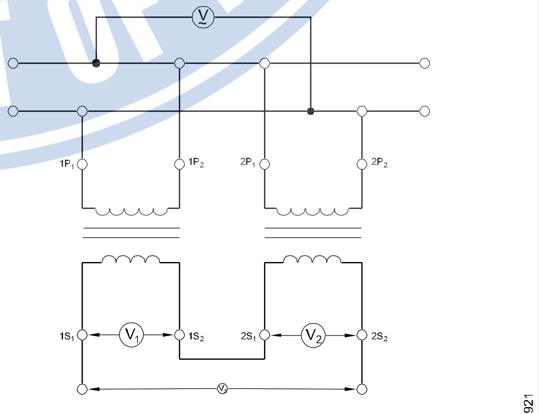
The connection diagram for series operation (secondary only) of two identical transformers is given below (Fig 1)

Necessity for series operations:

In general, the transformers are available with some standard input (primary) and output (secondary) voltages. In order to get some intermediate voltage for example , 36V, 48 V for special purpose, the series operation of transformers (secondary only) are necessary.

In series operation, individual secondary voltages of both transformers are added if they are connected with proper polarity, but the current ratings are remains same.

Fig 1



SERIES OPERATION OF TRANSFORMERS
(SECONDARY ONLY)

Condition for series operation:

Both transformers should be identical i.e,

a) Voltage ratio/turns ratio must be same

b) Polarities must be same

c) Type of core of both transformers (core or shell type) must be same.

d) Input voltages of both transformers must be same.

e) KVA ratings of both transformers must be same.

f) Percentage impedance or per unit impedance of both the transfers must be same.

Precautions:

- **The polarities of secondary of both transformers should be connected in proper way, same as series connection, to get the voltage added, otherwise the output voltage will be zero.**
- **As the output voltage is double that the individual secondary voltages, care to be given to ascertain the insulation level of the secondary windings.**

Three Phase transformer - Connections

Objectives: At the end of this lesson you shall be able to
- **state the transformer connections, angular divergence of the 3 phase transformers**
- **explain the scott connection of transformer and its uses.**

Transformer Bank

Transformers, like other electrical devices, may be connected into series, parallel, two-phase or three-phase arrangements. When they are grouped together in any of these arrangements the group is called a transformer bank.

The high voltage and low voltage winding terminals of a three-phase transformer are connected either in star or in delta for connections to a three-phase system.

When the primary high voltage winding terminals are connected in, say, star and the secondary low voltage winding terminals are connected in, say, delta, it is said that the transformer windings are connected in star-delta (U - D or U - d). Similarly

star-star (Uy)

delta-delta (Dd)

and, delta-star (Dy) connections can be used.

Type of connection	High voltage side	Low voltage side
Delta	D	d
Star	U	y
Zigzag	Z	z

Angular displacement (divergence)**:** There is a definite time phase relationship between the terminal voltages of the high voltage side and low voltage side for these connections. The time phase relationship between the voltages of high voltage side and low voltage sides will depend upon the manner in which the windings are connected.

If the high voltage side and low voltage side windings are connected in star-star (as in Fig 1a and 1b). The phase displacement will be zero. If, however, the low voltage winding connections are reversed, as shown in Figs 2(a) and (b), the time phase displacement in induced voltages between the high voltage and low voltage windings will be 180 degrees.

If the primary high voltage and secondary low voltage side windings are connected in Yd or Dy as shown in Figs 3(a) and (b), the phase displacement will be - 30 degrees.

The displacement in the clockwise direction is negative. Anti clockwise is positive.

Fig 1

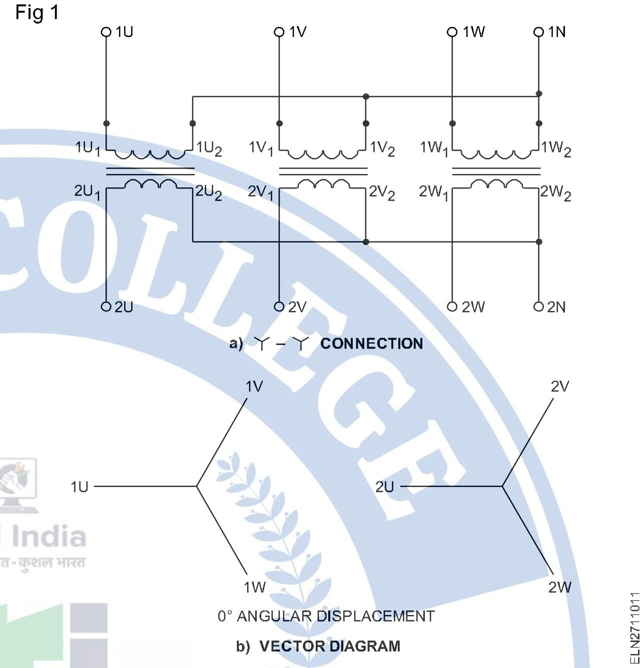
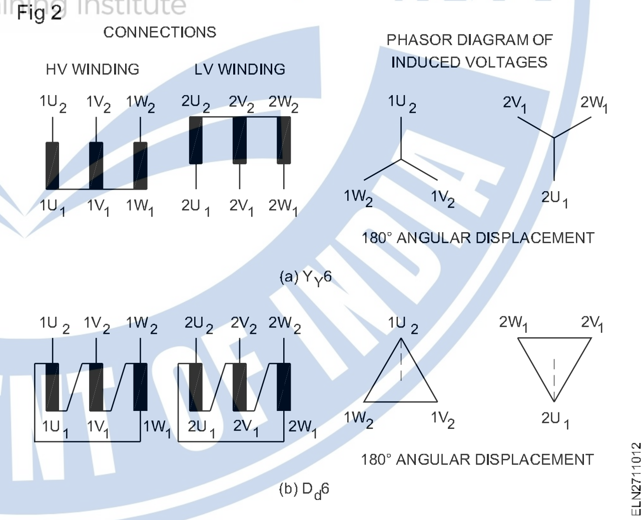


Fig 2



If the windings are connected in Yd or Dy as Figs 4 (a) & (b), the displacement of the terminal voltage will be + 30°.

Observe the change in connections made at the low voltage side in Figs 3(a) and Fig 4(a). Similarly the change in the high voltage side winding connections Figs 3(b) and Fig 4(b) causes the difference in displacement angle.

Fig 3

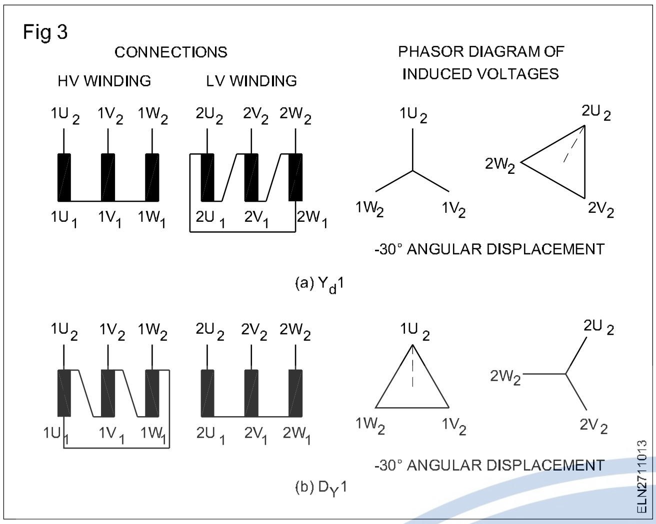
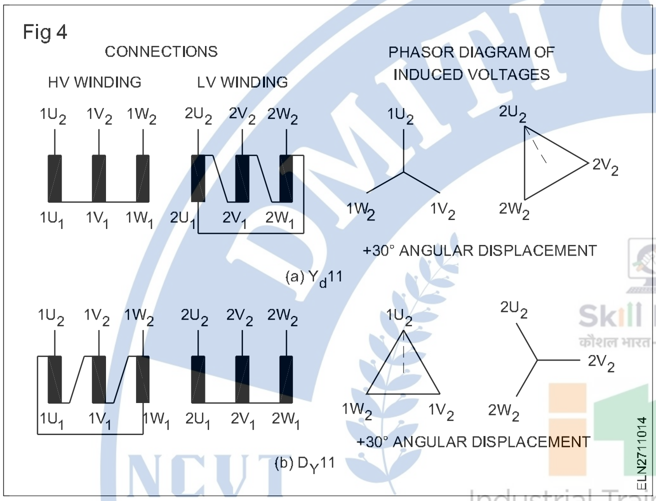


Fig 4



Scott connection or T.T. connection: In certain special equipment the line voltage required for its 3-phase connection may not be of standard rating as available in the system. Further, the power consumption in these equipment may also be high. To meet this requirement Scott connected transformers are used. These Scott connected transformers enable transformation of 3-phase to 3-phase more economically.

This Scott connection can also be used for 3-phase to 2-phase transformation as explained subsequently.

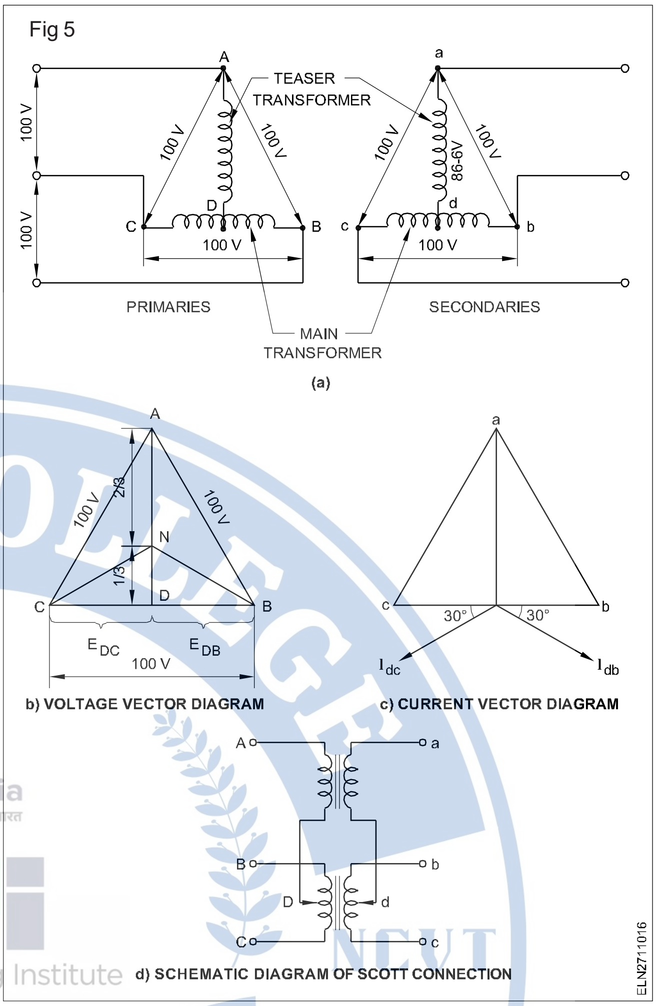
The main transformer has centre tapped primary and secondary windings Fig 5. The primary and secondary windings are indicated by CB and cb respectively in the Fig 5. Another transformer called teaser transformer has a 0.866 tap and one end of both the primary and secondary windings of the teaser transformer (say D and d) is joined to the centre tap of both primary and secondary of the main transformer.

The other end A of the teaser transformer and the two ends B and C of the main transformer primary are connected the 3-phase supply.

3-phase supply is taken out from one end 'a' of the teaser transformer secondary and the two ends b and c of the secondary of the main transformer.

For convenience unity transformation ratio is choosen and the supply line voltage is assumed as 100V (Fig 5).

Fig 5



(a)

b) VOLTAGE VECTOR DIAGRAM

c) CURRENT VECTOR DIAGRAM

d) SCHEMATIC DIAGRAM OF SCOTT CONNECTION

By analysing the vector diagram Fig 5b, it is found that voltage E_{DC} and E_{DB} are each 50V and differ in phase by 180^0 because both the coils DB and DC are in the same magnetic circuit and are connected in opposition. Fig 5d shows the schematic connection diagram.

Each side of the equilateral triangle represents 100V. The voltage E_{DA} being the altitude of the equilateral triangle is equal to $\sqrt{3}/2 \times 100 = 86.6V$ and legs behind the voltage across the main by 90^0. The same relation holds good for the secondary voltages. The transformer rating is restricted to 86.6% of its KVA rating. By suitable turn ratio the trnsformer rating can be improved to 92.8%.

3-phase to 2-phase conversion and vice versa: In industrial application of electric power supply certain equipment like electric furnaces and welding transformers require two phase supply.

At present, the available electrical supply is in variably three phase it is necessary to convert the 3 phase supply to 2 phase supply. This is accomplished by Scott connection.

Three single phase transformers for three phase operation

Objectives: At the end of this lesson you shall be able to
- **list and interpret the four types of connections of primary and secondary windings**
- **state the phase and line values of current and voltage.**

There are various methods available for transforming 3-phase voltages, that is for handling a considerable amount of power. There are four possible ways in which the primary and secondary windings of a group of three transformers may be connected together to transfer energy from one 3-phase circuit to another. They are:

Primaries in Y, Secondaries in Y

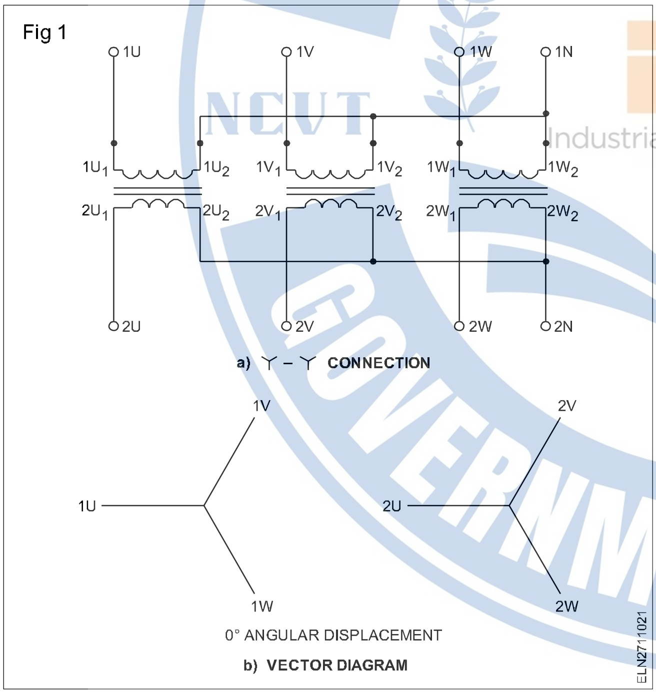
Primaries in Y, Secondaries in Δ

Primaries in Δ, Secondaries in Δ

Primaries in Δ, Secondaries in Y.

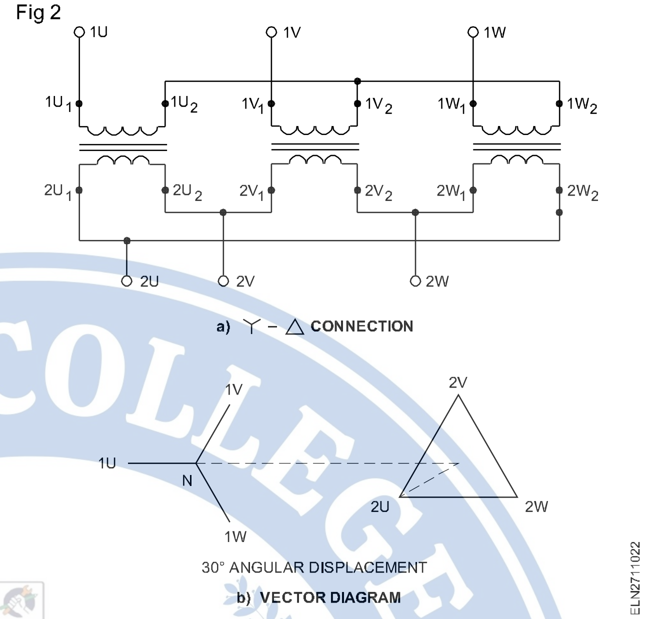
Star/Star or Y/Y connection: Fig 1 shows the connection of a bank of 3 trans-formers in a star-star. This connection is most economical for small, high voltage transformers because the number of turns per phase and the amount of insulation required is minimum. This connection works satisfactorily only if the load is balanced. For a given voltage V between lines, the voltage across the terminals of a Y connected transformer is $V/\sqrt{3}$; the coil current is equal to the line current I.

Fig 1



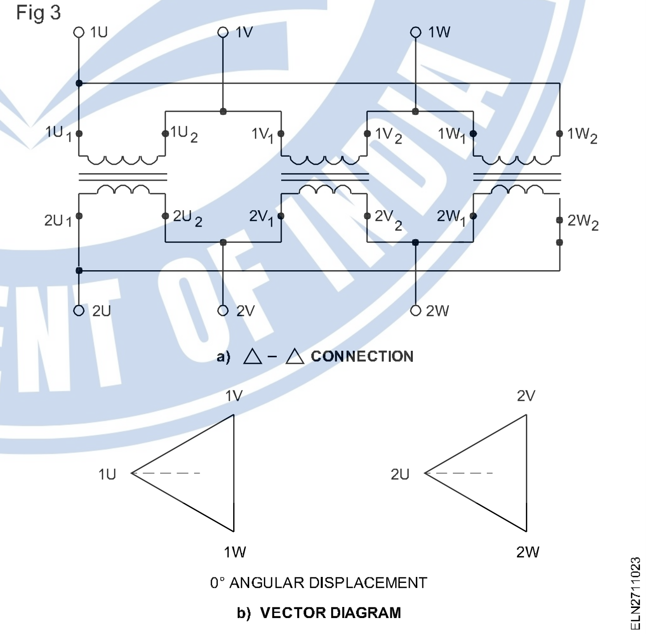
Star - Delta or Y/Δ connection: In primary side 3 transformers are connected in star and the secondary consist of their secondary connected in delta as shown in Fig 2. The ratio between the secondary and primary line voltage is $1/\sqrt{3}$ times the transformation ratio of each transformer. There is a 30° shift between the primary and secondary line voltages. The main use of this connection is at the substation end of the transmission line.

Fig 2



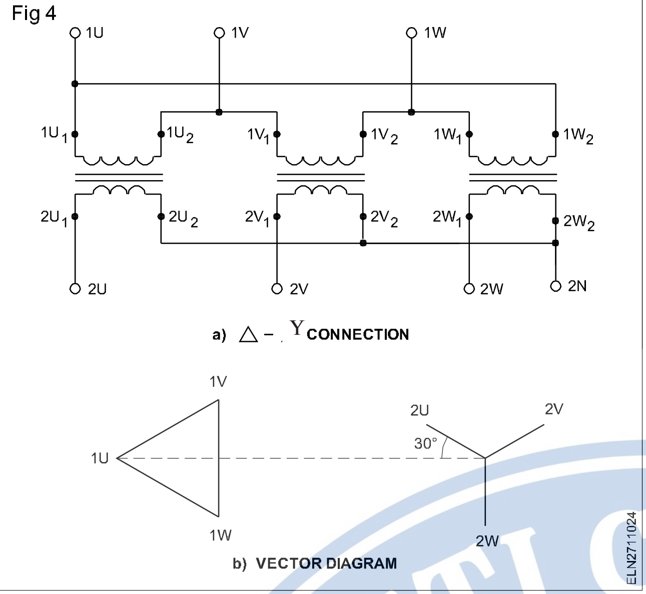
Delta - Delta or Δ/Δ connection: Fig 3 shows three transformers, connected in Δ on both primary and secondary sides. There is no angular displacement between the primary and secondary line voltages. An added advantage of this connection is that if one transformer becomes disabled, the system can continue to operate in open-delta or in V-V. In V-V it can be operated with a reduced capacity of 58% and not 66.6% of the normal value.

Fig 3



Delta - Star or Δ/Y connection: (Fig 4) This connection is generally employed where it is necessary to step up the voltage, as for example, at the beginning of high tension transmission system.

Fig 4



The primary and secondary line voltages and line currents are out of phase with each other by 30°. The ratio of secondary to primary voltage is $\sqrt{3}$ times the transformation ratio of each transformer.

Parallel operation of 3-phase transformer

Objectives: At the end of this lesson you shall be able to

- **explain parallel opration**
- **states the conditions for parallel operation of 3 phase transformer**
- **sates the necessity of parallel opertion.**

Parallel operation

Operating two or more transformers by connecting their primaries in parallel to a common supply line and connecting their respective secondaries in parallel with a common load-busbars is called as parallel operaion of transformers.

Conditions for pararllel opertion of transformers:

When operating two or more transformer in parallel, the following conditions have to be satisfied for the best performance of the transformer.

1 The voltage ratio must be same.

2 The per unit impedance or percentage impedance should be same i.e., the ratio between the equivalent leakage reactance and the equivalent resistance(X/R)should be same.

3 The polarities must be same.

4 For three phase transformers

   i The phase sequence must be same

   ii The vector group must be same (i.e., The relative phase displacement between the secondary line voltages must be zero)

Parallel operation of 3-phase transformer:

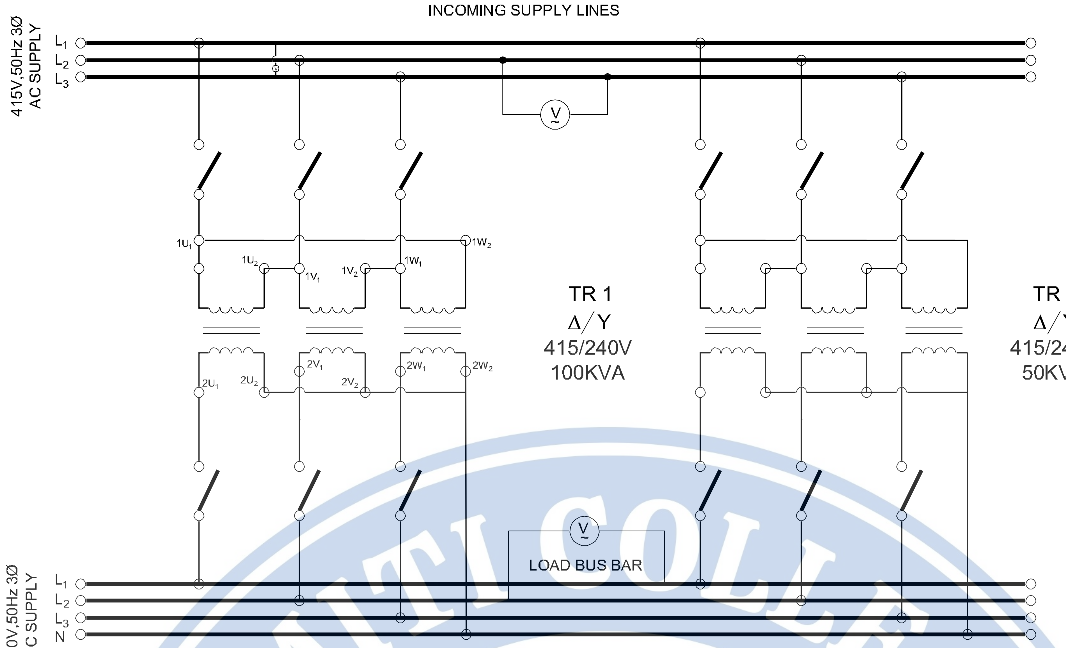
Fig 1 shows the connection diagram for parallel operation of two numbers of 3-phase transformers. In this case, the connection of both of transformer 1 and 2 are (delta - star)same.

However to operate the 2 transformers of having Y/Δ and connection, their primary and secondary line voltage Δ/Y must be same. In this case,the turns ratio may not be equal, but the voltage ratio between the terminal voltage of primary and secondary must be same.

If two transformers having different ratings, are connected in parallel the their percentage impedance must be same, where as the numerical impedance of transformer 1 will have half the impedance of transformer 2. In this case both the transformers will share the common load in propertional to their KVA ratings.(Fig 1)

For best performance of the parallel operation, the regulation of both the transformers must be same . If the percentage impedance of both the transformers are different. Than one transformer will be operating at a higer power factor and other will be operating at a lower power factor.

Fig 1



PARALLEL OPERATION - 3 PHASE TRANSFORMER - CONNECTION DIAGRAM

Cooling of transformer - Transformer oil and testing

Scan the QR Code to view the video for this exercise

Objectives: At the end of this lesson you shall be able to
- **explain the necessity of cooling**
- **state the methods of cooling.**

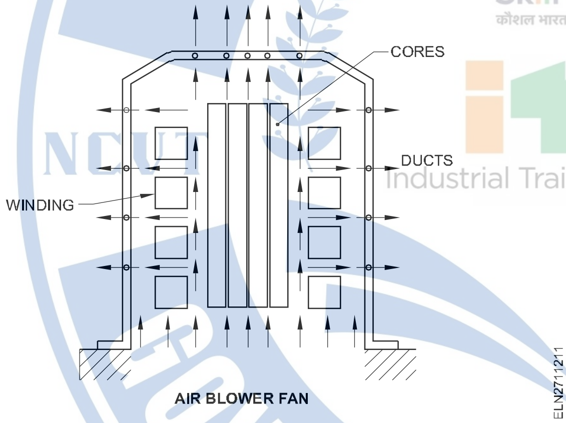
Necessity of cooling

Transformer is heated up when current flows through its, winding. This causes the liberation of heat. In large size transformer, where power rating is high, large amount of heat is liberated. This will affect the insulation of the windings as well as reduction of transformer efficiency. This heat should be transformed from transformer winding and dissipated in the atmosphere .

Methods for cooling transformers: Following are the methods of cooling employed in transformers. Any one or more methods could be adopted depending upon the size, application and location of the transformer.

- Natural air method
- Air blast method (Fig 1)

Fig 1

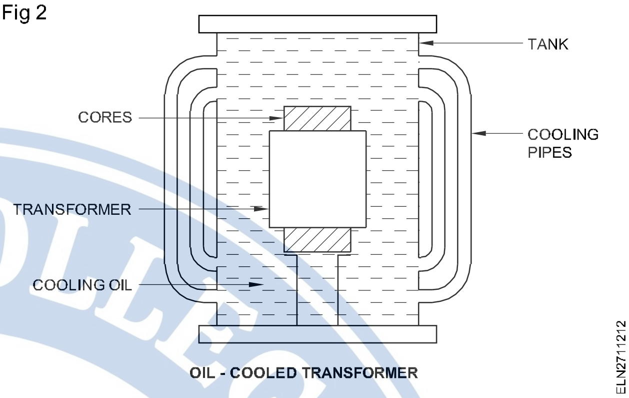


AIR BLOWER FAN

- Natural oil cooled method (Fig 2)
- Oil blast method
- Forced circulation of oil
- Oil and water cooled (Fig 3) and
- Forced oil and water cooled

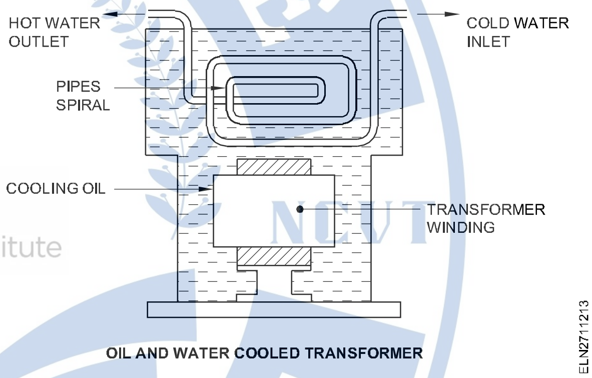
Natural air cooling method is generally adopted for low capacity distribution transformer upto 100KVA. The natural circulation of the surrounding air is used to carry away the heat from the transformer winding.

Fig 2



OIL - COOLED TRANSFORMER

Fig 3



OIL AND WATER COOLED TRANSFORMER

In air blast method, the fans are used to blow the air on the surface of the transformer thereby the heat generated is carried away by the air blast.

Transformer of 200KVA above capacity are cooled by using an insulating oil. The winding and core are immersed in oil. The area of the tank is increased by using cooling tubes. (Radiator tubes)

In oil and water cooled system, the low pressure water tubes through the heated oil used to remove the heat from the transformer.

Testing of transformer oil

Objectives: At the end of this lesson you shall be able to
- **explain the transformer oil**
- **name three insulating oils used in transformer**
- **list the important properties of a transformers oil**
- **state the necessity of transformer oil**
- **state the causes for deterioration of oil**
- **explain the methods of testings the oil for its parameter.**

Transformer oil

It is an insulating liquid, used to cool and insulate the transformer windigs and core.A cooling liquid is also considered as a part of the transformer.

Three kinds of cooling oils/liquids are used in transformers today.

- Mineral oil (inflammable)
- Silicon liquids(low flammable) and
- Hydrocarbon liquids (non-flammable)

The common transformer oil is a mineral oil obtained by refining crude petroleum. Clean and dry mineral oil is an excellent insulator. Its loss by evaporation is small. But it is an inflammable liquid and readily absorbs moisture from the air. Great care should be taken to keep the oil away from flame and moisture.

Synthetic liquids do not catch fire easily. Synthetic liquids are therefore replace mineral transformer oils of those transformers used in

- underground mines
- refineries and hazardous location
- tunnels
- workshop and plants of metal processing theatres and cinemas etc.

Transformer oil consists of organic compounds, namely paraffin, naphthalene and aromatics. All these are hydro carbons, hence insulating oil/transformer oil/ synthetic transformer oil known as ASKARELS and PYROCLORE are also in use.

Properties of transformer oil

A good transformer oil should have the following properties.

1 High specific resistance so that high insulation resistance

2 Better heat conductivity, (i.e) higher specific heat.

3 High firing point, so that not to catch fire at low temperature.

4 Do not absorb moisture easily, when exposed to air.

5 Low viscosity

Necessity of transformer oil: Large capacity distribution transformers produces more heat due to losses like core losses and copper losses, on load. It is necessary to stablize the heat within temperature class by providing suitable insulating materials.

Transformer oil acts as a good electrical insulating material. Thus it reduces electrical break down. Transformer oil will also act as cooling agent. Thus it brings thermal stability to all the internal parts of transformer.

Causes for deterioration of transformer oil: When the oil cooled transformers are in use, the oils of the transformers are subjected to normal deterioration due to the conditions of the use.

For example

1 The oil may come in contact with the air, there by presence of moisture and dust in the oil. The presence of moisture is harmful and affects the electrical characteristics of oil and will accelerate deterioration of insulating materials.

2 Sediment and precipitable sludge may be formed on the winding and core surfaces. It will reduce the cooling rate and hence it may lead to deterioration of the insulating materials.

3 The presence of certain solid iron, copper and dissolved metallic compounds will increase the acidity. In such cases, the resistivity decreases, and electrical strength also decreases, and it is also the causes for deterioration of transformer oil.

Testing of transformer oil: For reliable use and maintenance of oil cooled transformer, the transformer oil shall be tested before initial filling of the oil as well as during service of the transformers. As per the test result it may be required to filter the transformer oil or in some cases, new oil may be recommended for safe and better maintenance of oil cooled transformers.

The following tests are conducted periodically to decide the performance of the transformer oil.

1 Field test of insulation oil

2 Crackle test of insulating oil

3 Dielectric test of insulating oil

4 Acidity test.

1 Field test of insulating oil

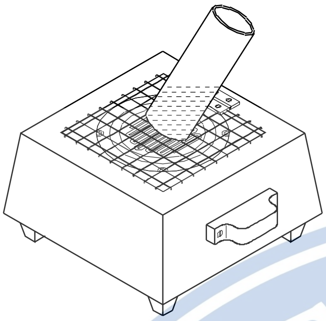
A drop of transformer oil, when placed slowly from a pipette on the still surface of a distilled water contained in heater should retain its shape when the oil is new.

In the case of used cyclo-octane oils (or) paraffin oils (even though unused) the drop usually flattened. If this flattened drop occupies an area of diameter less than 15 to 18 mm, the oil may be used. Otherwise, it has to be reconditioned. Oils with the longer spreads are unsuitable.

2 Crackle test of transformer oil (Fig1)

A rough test may be made, by closing one end of steel tube, and heating the closed end to just dull red hot. (Fig 1) When the oil sample is plunging into the tube, a sharp Crackle sound will be heard, if the oil contains much moisture. Dry oil will only sizzle.

Fig 1

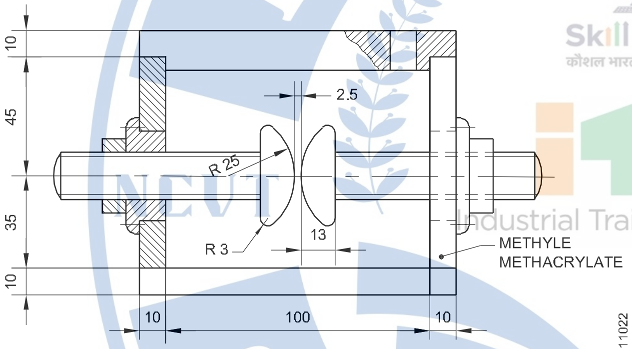


CRACKLE TEST

3 Dielectric test of transformer oil

This test is preferably conducted using standard oil test set. The oil test set consists of a container/cell made up of glass or plastic.(Fig 2)

Fig 2

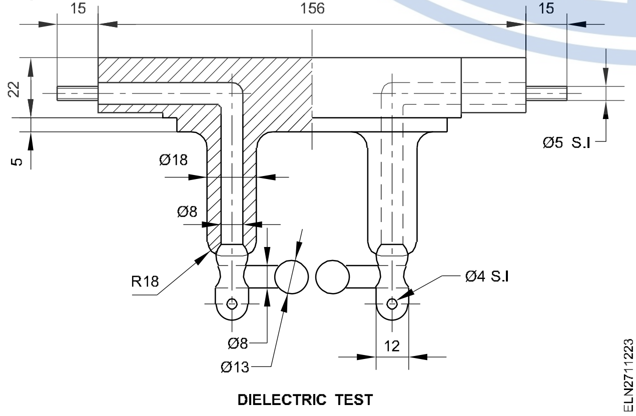


OIL TEST CONTAINER/CELL

The cell shall have an effective volume between 300 to 500 ml. It should be preferably closed. Section view of container. (Fig 3)

Two numbers of the copper, brass, bronze or stainless steel in the shape of sphere of diameter 12.5 to 13 mm elliptical are mounted on a horizontal axis at 2.5 mm apart, is used as electrodes, for oil test of 11KV transformer.

Fig 3



DIELECTRIC TEST

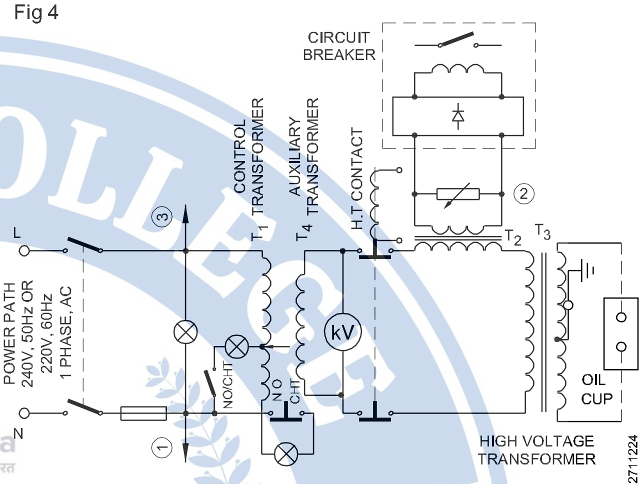
The cell is mounted on a test set. HT connection to the electrodes, is made by the point contact arrangements.

The test set is also provided into step up transformer where the voltage can be varied from zero to 60KV. In some designs, the voltage is varied by electric motor, with the operation of push button switch.

Electrical circuit diagram of dielectric test unit (Fig 4)

For conducting dielectric test on transformer oil, the oil is to be gently agitated and turned over several times so that homogeneous distribution of the impurities contained in the oil is spread all over.

Fig 4



CIRCUIT DIAGRAM OF DIELECTRIC TEST

Immediately after this, the oil is poured down into the test cell slowly in order to avoid air bubbles. The operation is carried out in a dry place free from dust. The oil temperature at the time of test shall be same as that of ambient.

After fulfilling the above conditions the cover of the cell is placed in position. The cell is placed in the test unit and power is switched "ON".

The AC voltage across the electrode of frequency 40 to 60Hz is increased uniformly at the rate of 2KV RMS starting from 'O' up to the value of producing break down. The break down voltage is the voltage reached during the test at the time the first spark occurs between electrodes.

The circuit is opened automatically if an arc is established between electrodes. The break down voltage is recorded and the reading is interpreted according to the standard ratings. The requirements as per IS-335-1983 is: Electrical Strength (break down voltage)

1	New unfiltered transformer oil	- 30KV (RMS)
2	After filtration transformer oil	- 50KV (RMS)

It is recommended to filter the transformer oil if the break down voltage does not attain 30KV (RMS).

The test shall be carried out 6 times on the same cell filling. The electric strength shall be the arithmetic mean of the 6 results which have been obtained.

4 Acidity test

The acid products are formed by the oxidation of the oil. This oxidation will deteriorate the insulating materials like insulating paper and press boards used in transformer windings. It is therefore essential to detect and monitor the acidity formation.

To conduct this test portable test kit is available consisting of:

1 Two polythene bottles containing 100ml each of ethyl alcohol and sodium carbonate solution of 0.0085N concentration.

2 An indicator bottle containing universal indicator.

3 Four clean glass test tube.

4 Three graduated droppers, which serves as pipettes.

5 Colour chart with acidity range.

6 Instruction booklet.

PROCEDURE

The test is conducted by taking 1.1 ml of insulating oil (to be tested) in test tube, 8 ml oil 1 ml of rectified spirit is added and mixture is to be gently shakened. Further 1 ml of solution of 0.008 5 N sodium carbonate added. After shaking the test tube once again 5 drops of universal indicator is added. The resulting mixture develops a colour depending on the acidity value of the mixture.

The approximate colour range will be as follows:

Total acidity value in No.	Colour
0.00	Black
0.2	Green
0.5	Yellow
1.0	Orange

Any how the colour chart will be provided with the test kit to indicate exact value.

Winding a small transformer

Objectives: At the end of this lesson you shall be able to
- **state the important data to be taken for rewinding the transformer**
- **explain the rewinding procedure for small transformers**
- **calculate the number of turns per volt using the formula and determine primary and secondary turns**
- **determine the dimensions of the transformer, size of bobbin and size of winding wire**
- **explain the tests to be carried out after winding the transformer.**

Scan the QR Code to view the video for this exercise

Rewinding of small transformer

It is necessary to rewind a transformer when the winding is burnt out or badly damaged.

While dismantling transformers, care should be taken to record the necessary particulars (data) by which the rewinding process becomes easy and the original performance of the transformer is assured.

Recording the data : The following data have to be taken from the transformer before and during disassembling.

1 Number of windings/turns/ layers.
2 Size of wires and insulation.
3 Input/output voltages & currents.
4 KVA ratings.
5 Conncetion diagrams.
6 Terminal marking / lead position
7 Types of cores / number of stampings
8 Physical condition of bobin / core.
9 Insulation schemes like size and specification of bindings, layer,interlayer,inter windings, bobin,lead wires, sleeves etc.

If the old bobbin is reused for winding, it shall be cleaned well and shall be free from any break or crack. If a new bobbin is used it shall be checked with the stamping (core) for proper assembly to avoid too much air gap or too tight a fitting.

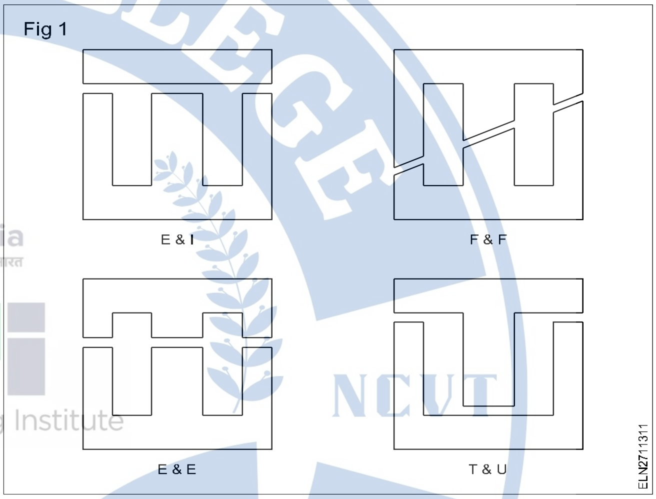
For winding, a suitable size of wire shall be selected from the data and the size of wire shall be measured as per I.S. 4800 (Part - I) 1968.

The size of the wire can be measured with insulation but it shall be within the limit of tolerance. The insulation scheme shall be followed as per the data taken. Where proper material is not available an equivalent type and size may be selected. Turns and tapping of the winding shall be made as in the original.

Method of stacking : Before stacking the core, stampings shall be checked for dents, bends and core insulation. Dents on the core shall be removed, and any mangled core shall be set right. Stacking shall be done as in the original sequence and pattern.

All the stampings available for the transformer shall be stacked without leaving out any. Fig 1 shows the different shapes of cores used for a shell type transformer. Leads shall be properly sleeved and terminated.

Fig 1



Procedure of rewinding a transformer: As stated above, if all the necessary winding details are obtained while disassembling the burnt out transformer, the rewinding procedure is more or less easy. However, if you have to prepare a new transformer the following information will be of great help.

Designing a transformer : Small transformers are generally of 'SHELL TYPE'. In shell type, both the primary and secondary windings are mounted on the centre limb of the core. For designing of a small power transformer proceed as stated below.

STEP NO.1

Find the total output power from the load voltage and current of the transformer.

$P_2 = E_2 \times I_2$ ....Formula 1.

The following example is given for your guidance.

Primary voltage - 240 V

Secondary voltage - 6V

Secondary total current - 2A

From the example the output power is calculated as 6 x 2 = 12VA.

STEP NO.2

Find the input watts.

$$P_1 = \frac{P_2}{\%\,\text{Efficiency}} \qquad \text{....... Formula 2}$$

Normally the efficiency of a transformer will be 80 to 90. As in the example

$$P_1 = \frac{6 \times 2 \times 100}{80} = 15 \text{ VA.}$$

STEP NO.3

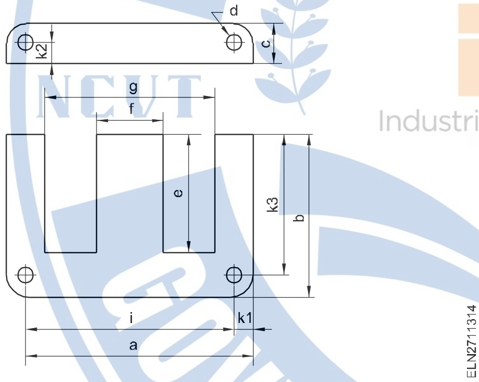
Determine the required cross-sectional area of the core of the transformer.

For finding the cross-sectional area, certain parameters like the flux density of the metal used for laminations, frequency of supply, allowable current density in the winding wire and power input to the transformer need to be known.

Cross section = 20 x 21=420 sq.mm or 4.2 sq. cm

Table 1 gives the standard size of stampings having E and I type laminations as available in the market which is given for your guidance. Fig 2 gives the dimensions of the stampings.

Fig 2



For the core area 4.248 sq.cm we can use the core of dimension having 20 mm as width and core thickness of 21mm.

The nearest size sheet should be selected from the standard size of the stamping table. Here we assume the centre limb width to be 20 mm, and hence, the core E.I. 60 is selected. However, you may select any other type to suit the cross-section. But the other details like the number of stampings and the bobbin dimensions may change accordingly.

STEP NO.4

The next step is to calculate the voltage per turn using Formula 4.

$e = 4.44 \times B \times A \times f \times 10^{-4}$ ....Formula 4.

where e - voltage per turn

B - flux density in tesla

A - area of iron core in cm^2

f - frequency in Hertz

Example

$e = 4.44 \times 0.8 \times 4.24 \times 50 \times 10^{-4} = 0.0753$ volts.

STEP NO.5

Calculate the primary coil turns.

$$N_1 = \frac{240}{0.0753} = 3187 \text{ turns (approx.)}$$

Calculate the secondary coil turns.

$$N_2 = \frac{6}{0.0753} = 80 \text{ turns (approx.)}$$

Add 10% to compensate the voltage drop (internal) in the secondary winding i.e. N_2 = 88 turns.

STEP NO.6

Calculate the size of wire with respect to the input power.

P = E x I ; I = P/E and according to the example,

Primary current = I_1 = 15/240 = 0.0625A

Secondary current = I_2 = 15/6 = 2.5A.

Cross-section of primary conductor considering $3A/mm^2$ as current density will be

A = 0.0625/3 = 0.020833 mm^2

Diameter = 0.1628 mm

Say i.e. = 0.160 mm dia. or 37 SWG approximately

Cross-section of secondary conductor considering $3A/mm^2$ as current density will be

A = 2.5/3A = 0.8333 mm^2

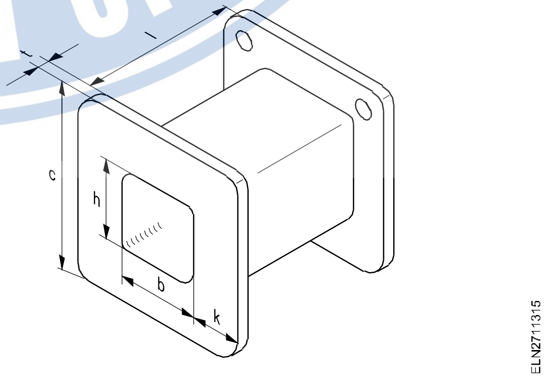
Diameter = 1.029 mm

Say = 1.00 mm dia. Hence 19 SWG.

STEP NO.7

Fig 3 gives the general dimensions of a bobbin. Here the bobbin selected is EI 60/21 which suits the core thickness of the centre limb taken earlier as 21 mm and core width as 20 mm.

Fig 3



STEP NO.8 : Check the feasibility of accommodating the number of turns of primary and secondary within the winding space.

Though the number of turns in the primary is to be 3187 of 37 SWG and the secondary to be 88 turns of 19 SWG super enamelled copper wire, it is atmost important to check whether these windings along with the respective insulation could be accommodated within the winding space of the core. This has to be determined before taking up the winding.

CONCLUSION : For the transformer as in the example, the derived winding data is as follows.

Transformer rating
Primary - 240V
Secondary - 6V
Frequency - 50 Hz
Volt ampere input - 15 VA

Core : Core area 20 x 21 mm as decided in Step 3.

Bobbin: Breadth 20.6 mm, height 21 mm, length 26.7 mm and the total height of the flange 42.7 mm as decided in step 7.

Wire sizes and turns

Primary - 3187 turns of size 0.16 mm or 37 SWG
Secondary - 88 turns of size 1.00 mm or 19 SWG

Stampings: Considering the thickness of each stamping as 0.35 mm, for the total thickness of 21 mm we may require 60 stampings. Considering the space between stampings and the stacking we may require 55 stampings only. Hence EI 60/21 type 55 numbers of stampings having 0.35 mm thickness are to be procured.

Testing of transformer after rewinding: After rewinding the core assembly, the transformer is to be inspected for proper tightness of the core and coil as well as proper termination of the end leads.

Insulation resistance test : Insulation resistance is measured between windings and core with a 500 volts Megger. The reading so obtained shall be infinity and in no case below one megohm.

Transformation ratio test: Keeping the transformer secondary open, the primary shall be connected to the rated AC voltage. With the help of suitable voltmeters both the primary and secondary voltage shall be measured.

Load test : The transformer shall be connected with a suitable load, so that the full load secondary current flows through the secondary of the transformer winding. The raise in the winding temperature shall be observed by a suitable industrial thermometer, on the load.

The transformer temperature will raise initially and after some time the temperature will come to a standstill. This raise in temperature shall be noted and it shall be within the limit of class of insulation of the transformer designed.

Short circuit test : Where it is not possible to load the transformer directly, the secondary winding of the transformer shall be short circuited and the low voltage on the primary shall be adjusted through a dimmerstat so that full load secondary current flows through the secondary winding of the transformer. The transformer so switched on shall be tested for raise in temperature to ascertain the class of insulation.

Generally oil-cooled transformers are of class-A where-as air-cooled transformers may be class 'A' or 'E'.

Table 1
Standard size of stampings

Specification of stampings	a	b	c	d	e	f	g	i	k1	k2	k3
EI42	42	28	7	3.5	21	14	28	35	3.5	—	24.5
EI48	48	52	8	3.5	24	16	32	40	4	—	28
EI54	54	36	9	3.5	27	18	36	45	4.5	—	31.5
EI60	60	40	10	3.5	30	20	40	50	5	—	35
EI66	66	44	11	4.5	33	22	44	55	5.5	—	38.5
EI78	78	52	13	4.5	39	26	52	65	6.5	—	45.5
EI84	84	56	14	4.5	42	28	56	70	7	—	49
EI92	92	62.3	11.3	4.5	51	23	69	82	5	6.5	57.5
EI106	106	70.5	14.5	5.5	56	29	77	94	6	8.5	64.5
EI130	130	87.5	17.5	6.8	70	35	95	115	7.5	10	80
EI150	150	100	20	7.8	80	40	110	135	7.5	12.5	92.5
EI170	170	117.5	22.5	8	95	45	125	150	10	12.5	107.5
EI195	195	134.5	25.5	9.5	109	51	144	171	12	13.5	122.5
EI231	231	166	29	10	137	58	173	204	13.5	15.5	152.5

Nominal thickness of stampings:0.35 mm and 0.5 mm.

General maintenance of three-phase transformers

Objectives: At the end of this lesson you shall be able to
- **explain the need and advantages of maintenance of transformer**
- **state the factors affecting the life of transformers**
- **state the various periodical maintenance to be carried out in a transformer.**

Necessity of maintenance

Power transformer is required to give a long and trouble free service, It should be under constant attention and maintenance as it is a costly device.

A rigid system of inspection and preventive maintenance will ensure long life, trouble free service and low maintenance cost. Maintenance shall consists of regular inspection, testing and reconditioning wherever necessary.

Principal object of maintenance: The principal object of maintenance is to maintain the insulation in good condition. Moisture, dirt and excessive heat in contact with oxygen are the main causes of insulation deterioration and avoidance of these will keep the insulation in good condition.

There will be a decline in the quality of insulation during the ageing process due to chemical and physical effects. The decay of the insulation follows the chemical reaction rate and if the sustained operating temperature exceeds the normal operating temperature of 75^0C by about 10^0C the life of the transformer will get shortened.

FACTORS AFFECTING THE LIFE OF TRANSFORMERS

1 Effect of moisture

Transformer oil readily absorbs moisture from air. The effect of water in the oil is to decrease the dielectric strength of the oil. Therefore preventive steps should be taken to guard against moisture penetration to the inside of transformers. This will include blocking of all openings for free access of air and frequent reactivation of breathers in service.

2 Effect of oxygen

Oxygen present inside the transformer due to air in oil, reacts on the cellulose of insulation. Due to decomposition of the cellulose product, an organic acid soluble in oil is formed which will lead to a thick sludge. This sludge blocks the free circulation of the oil and deposited in bottom there by causing damage to coils/cores.

3 Effect of solid impurities

The dielectric strength of oil is diminished by minute quantities of solid impurities present in the oil. It is therefore a good practice to filter the oil after it has been in service for a short time.

4 Effect of varnishes

Some varnishes particularly of oxidizing type reacts with transformer oil and precipitate sludge on the windings. This should be kept in mind by the maintenance engineer when rewinding and replacing the coils during repairs.

5 Effect of slackness of windings

Slackness of windings may cause a failure due to repeated movement of coils which may wear the conductor insulation at some places and lead to an inter turn failure, momentary short circuit which may cause electric and magnetic unbalance. It is a good practice to lift the core and windings of a transformer and take up any slackness which may have developed by tightening the tie rods.

MAINTENANCE PROCEDURE

1 Safety precautions

i Before starting any maintenance work the transformers should be isolated from the supply and the terminals are earthed.

ii The oil level should be noted before unsealing the tank.

iii No fire should be kept near the transformer while maintenance work is going on.

2 Breather

Generally two types of breathers are used namely

a) Silicagel breather

b) Oil filled silicagel breather

a Silica gel breather

The colour of the crystals changes from blue to pink as the crystals absorbs moisture. When the crystals gets saturated with moisture they become predominantly pink and it should be reactivated / reconditioned.

b Oil filled silicagel breather

Oil available in the oil chamber attached with silicagel breather should be replaced, if it is gel condeminated.

External connections: All terminal connections should be tight. If they appear blackened or corroded, remove the connection and clean down to bright metal with emery paper. Remake the connection and give it a heavy coating of grease.

Earth connections: All earth connections should be properly maintained. A small copper loop to bridge the top cover of the transformer and the tank may be provided to avoid earth fault current passing through the bolts when there is a lightening surge, high voltage surge or failure of bushings.

Bushings: Clean the bushing projection and examine them for cracks and chips. It is recommended to have a spare in stock. In transformers located in control areas to avoid salt formation, a thin coating of grease pasted on the bushings.

Recommended maintenance schedules for transformers of rating less than 1000 KVA is given in Table 1.

Table 1

Maintenance schedule for transformers of capacities less than 1000 KVA

Sl.No.	Inspection Frequency	Items to be inspected	Inspection Notes	Action required during inspection if defects are noticed
1	Hourly	Load (Amperes)	Check against rated figures	Regulated with the values
2	Hourly	Voltage	- do -	- do -
3	Daily	De-hydrating breather	Check that air passages are clear. Check the colour of silica gel.	If silicagel is pink colour replace it or reactivate it.
4	Monthly	Oil level in transformer	Check transformer oil level	If low top-up with dry oil. Examine for oil leakage.
5	Quarterly	Bushings	Examine for cracks and dirt deposits	Clean or replace.
6	Half-yearly	Non-conservator transformer	Check for moisture under cover	Improve ventilation. Check oil
7	Yearly	Oil in transformer	Check dielectric strength acidity and sludge	Restore the quality of oil
8	Yearly	Earth resistance	Check the connection - nuts & bolts	Take suitable action if earth resistance is high.
9	1 year	Relay, alarms their circuits etc.	Examine relay and alarm contacts, their operation fuses etc.,check relay accuracy.	Clean the components, replace contacts change the setting if required
10	2 year	Non-conservator transformers	Internal Inspection	Filter oil regardless of condition
11	3 year	All parts	Overall inspection by lifting of core and coils	Wash by Flushing down with clean dry oil.